



US Army Corps  
of Engineers

TECHNICAL REPORT CERC-90-13

## ANNUAL DATA SUMMARY FOR 1988 CERC FIELD RESEARCH FACILITY

### Volume I

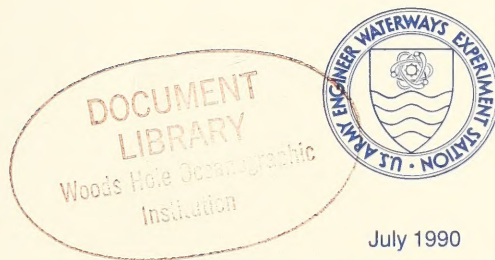
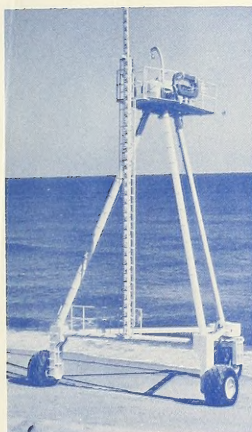
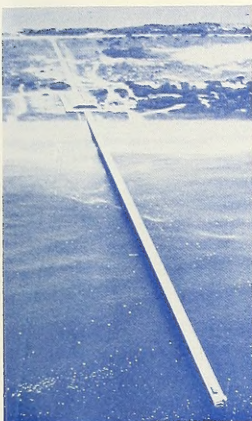
### MAIN TEXT AND APPENDIXES A AND B

by

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| <p>This report provides basic data and summaries for the measurements made during 1988 at the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, NC. The report includes comparisons of the present year's data with cumulative statistics from 1980 to the present.</p> <p>Summarized in this report are meteorological and oceanographic data, monthly bathymetric survey results, samples of quarterly aerial photography, and descriptions of 16 storms that occurred during the year. The year was highlighted by a severe storm in April that destroyed several oceanfront cottages. Waves with 5-m significant height were measured 6 km from shore.</p> <p style="text-align: right;">(Continued)</p> |  |  |  |
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19. ABSTRACT (Continued).

This report is tenth in a series of annual summaries of data collected at the FRF that began with Miscellaneous Report CERC-82-16, which summarizes data collected during 1977-1979. These reports are available from the WES Technical Report Distribution Section of the Information Technology Laboratory, Vicksburg, MS.

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## PREFACE

This report is the tenth in a series of annual data summaries authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32525, Field Research Facility Analysis, Coastal Flooding Program. Funds were provided through the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), under the program management of Dr. C. Linwood Vincent, CERC. Mr. John H. Lockhart, Jr., was HQUSACE Technical Monitor.

The data for the report were collected and analyzed at CERC's Field Research Facility (FRF) in Duck, NC. The report was prepared by Mr. Michael W. Leffler, Computer Programmer Analyst, FRF, under the direct supervision of Mr. William A. Birkemeier, Chief, FRF Group, Engineering Development Division (EDD), and Mr. Thomas W. Richardson, Chief, EDD; and under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively. Mr. Kent K. Hathaway, Oceanographer, FRF, assisted with instrumentation; and Mr. Brian L. Scarborough, Amphibious Vehicle Operator, FRF, assisted with data collection. Messrs. Herman C. Miller, Clifford F. Baron, John B. Strider, Jr., James E. Martin, and Mark A. McConathy and Meses. Deborah R. Heibel and Wendy L. Smith assisted with data analysis at the FRF. The National Oceanic and Atmospheric Administration/National Ocean Service maintained the tide gage and provided statistics for summarization.

Commander and Director of WES during the publication of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

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\* A limited number of copies of Appendixes C-E (Volume II) were published under separate cover. Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

## ANNUAL DATA SUMMARY FOR 1988

### CERC FIELD RESEARCH FACILITY

#### PART I: INTRODUCTION

##### Background

1. The US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF), located on 0.7 km<sup>2</sup> at Duck, NC (Figure 1), consists of a 561-m-long research pier and accompanying office and field support buildings. The FRF is located near the middle of Currituck Spit along a 100-km unbroken stretch of shoreline extending south of Rudee Inlet, VA, to Oregon Inlet, NC. The FRF is bordered by the Atlantic Ocean to the east and Currituck Sound to the west. The Facility is designed to (a) provide a rigid platform from which waves, currents, water levels, and bottom elevations can be measured, especially during severe storms; (b) provide CERC with field experience and data to complement laboratory and analytical studies and numerical models; (c) provide a manned field facility for testing new instrumentation; and (d) serve as a permanent field base of operations for physical and biological studies of the site and adjacent region.

2. The research pier is a reinforced concrete structure supported on 0.9-m-diam steel piles spaced 12.2 m apart along the pier's length and 4.6 m apart across the width. The piles are embedded approximately 20 m below the ocean bottom. The pier deck is 6.1 m wide and extends from behind the dune-line to about the 6-m water depth contour at a height of 7.8 m above the National Geodetic Vertical Datum (NGVD). The pilings are protected against sand abrasion by concrete erosion collars and against corrosion by a cathodic system.

3. An FRF Measurements and Analysis Program has been established to collect basic oceanographic and meteorological data at the site, reduce and analyze these data, and publish the results.

4. This report, which summarizes data for 1988, continues a series of reports begun in 1977.



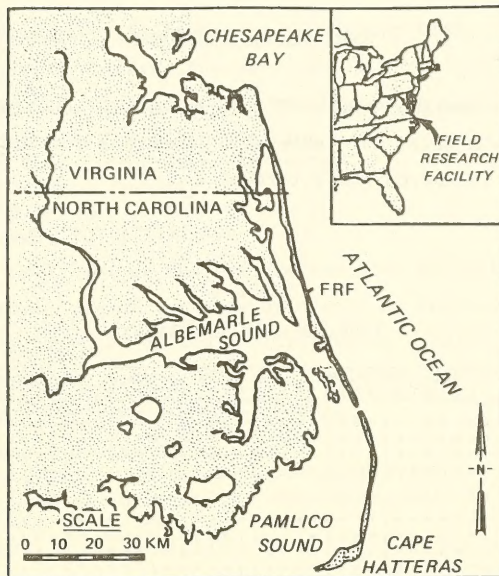


Figure 1. FRF location map

### Organization of Report

5. This report is organized into nine parts and five appendixes. Part I is an introduction; Parts II through VIII discuss the various data collected during the year; and Part IX describes the storms that occurred. Appendix A presents the bathymetric surveys, Appendix B summarizes deep-water wave statistics, and Appendixes C through E (published under separate cover as Volume II) contain summary statistics for other gages.

6. In each part of this report, the respective instruments used for monitoring the meteorological or oceanographic conditions are briefly described along with data collection and analysis procedures and data results. The instruments were interfaced with the primary data acquisition system, a Digital Equipment Corporation (Maynard, MA) VAX-11/750 minicomputer located in the FRF laboratory building. More detailed explanations of the design and the operation of the instruments may be found in Miller (1980). Readers' comments on the format and usefulness of the data presented are encouraged.

## Availability of Data

7. Table 1 summarizes the available data. In addition to the wave data summaries in the main text, more extensive summaries for each of the wave gages are provided in Appendixes B through E.

Table 1  
1988 Data Availability

| Gage                  | Jan       | Feb     | Mar     | Apr       | May     | Jun     | Jul       | Aug     | Sep     | Oct       | Nov     | Dec     |
|-----------------------|-----------|---------|---------|-----------|---------|---------|-----------|---------|---------|-----------|---------|---------|
| ID                    | 1 2 3 4 5 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 5 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 5 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 5 | 1 2 3 4 | 1 2 3 4 |
| Weather               |           |         |         |           |         |         |           |         |         |           |         |         |
| Anemometer            | 632       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | *****   | *****   |
| Atmospheric Pres.     | 616       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | *****   | *****   |
| Air Temperature       | 624       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | *****   | *****   |
| Precipitation         | 604       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | *****   | *****   |
| Waves                 |           |         |         |           |         |         |           |         |         |           |         |         |
| Offshore Waverider    | 630       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | /       | ***     |
| Pressure Gage         | 111       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | *****   | *****   |
| Pier End              | 625       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | -       | -       |
| Pier Nearshore        | 645       | *****   | *****   | /         | ***     | /       | ***       | /       | *****   | *****     | /       | ***     |
| Currents              |           |         |         |           |         |         |           |         |         |           |         |         |
| Pier End              |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   |
| Pier Nearshore        |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   |
| Beach                 |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   |
| Pier End Tide Gage    |           | *****   | /       | *****     | /       | *****   | *****     | *****   | *****   | *****     | *****   | *****   |
| Water Characteristics |           |         |         |           |         |         |           |         |         |           |         |         |
| Temperature           |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | /       | *****     | *****   | *****   |
| Visibility            |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   |
| Density               |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | /       | *****     | *****   | *****   |
| Bathymetric Surveys   |           | *       |         | *         | *       |         | *         |         | *       |           | *       | *       |
| Photography           |           |         |         |           |         |         |           |         |         |           |         |         |
| Beach                 |           | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   | *****     | *****   | *****   |
| Aerial                |           | *       |         | *         |         |         |           | *       | *       | *         |         |         |

Notes: \* Full week of data obtained.  
/ Less than 7 days of data obtained.  
- No data obtained.

8. The annual data summary herein summarizes daily observations by month and year to provide basic data for analysis by users. Daily measurements and observations have already been reported in a series of monthly

Preliminary Data Summaries (Field Research Facility 1988). If individual data for the present year are needed, the user can obtain detailed information (as well as the monthly and previous annual reports) from the following address:

USAE Waterways Experiment Station  
Coastal Engineering Research Center  
Field Research Facility  
SR Box 271  
Kitty Hawk, NC 27949-9440

Although the data collected at the FRF are designed primarily to support ongoing CERC research, use of the data by others is encouraged. The WES/CERC Coastal Engineering Information and Analysis Center (CEIAC) is responsible for storing and disseminating most of the data collected at the FRF. All data requests should be in writing and addressed to:

Commander and Director  
US Army Engineer Waterways Experiment Station  
ATTN: Coastal Engineering Information Analysis Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180-6199

Tidal data other than the summaries in this report can be obtained directly from the following address:

National Oceanic and Atmospheric Administration  
National Ocean Service  
ATTN: Tide Analysis Branch  
Rockville, MD 20852

A complete explanation of the exact data desired for specific dates and times will expedite filling any request; an explanation of how the data will be used will help CEIAC or the National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) determine if other relevant data are available. For information regarding the availability of data for all years, contact CEIAC at (601) 634-2012. Costs for collecting, copying, and mailing will be borne by the requester.

## PART II: METEOROLOGY

9. This section summarizes the meteorological measurements made during the current year and in combination with all previous years. Meteorological measurements during storms are given in Part IX.

10. Mean air temperature, atmospheric pressure, and wind speed and direction were computed for each data file which consisted of data sampled two times per second for 34 min every 6 hr beginning at or about 0100, 0700, 1300, and 1900 eastern standard time (EST); these hours correspond to the time that the National Weather Service (NWS) creates daily synoptic weather maps. During storms, data recordings were made more frequently. The data are summarized in Table 2.

Table 2  
Meteorological Statistics

| Month   | Mean<br>Air Temperature<br>deg C |           | Mean<br>Atmospheric Pres.<br>mb |           | Precipitation, mm |           |        |        | Wind Resultants |                  |                |                  |
|---------|----------------------------------|-----------|---------------------------------|-----------|-------------------|-----------|--------|--------|-----------------|------------------|----------------|------------------|
|         | 1988                             |           | 1983-1988                       |           | 1988              | 1978-1988 |        |        | 1988            |                  | 1980-1988      |                  |
|         | 1988                             | 1983-1988 | 1988                            | 1983-1988 | Total             | Mean      | Maxima | Minima | Speed<br>m/sec  | Direction<br>deg | Speed<br>m/sec | Direction<br>deg |
| Jan     | 3.9                              | 5.0       | 1024.2                          | 1017.8    | 124               | 100       | 180    | 44     | 2.6             | 349              | 2.6            | 339              |
| Feb     | 6.1                              | 6.0       | 1018.8                          | 1017.3    | 86                | 72        | 86     | 20     | 1.2             | 313              | 1.8            | 350              |
| Mar     | 9.9                              | 9.1       | 1019.1                          | 1016.2    | 37                | 79        | 168    | 35     | 0.2             | 27               | 1.4            | 358              |
| Apr     | 13.6                             | 13.5      | 1010.8                          | 1013.2    | 100               | 95        | 182    | 0      | 1.4             | 354              | 0.4            | 319              |
| May     | 17.9                             | 18.8      | 1014.8                          | 1016.2    | 49                | 64        | 239    | 20     | 1.5             | 64               | 0.4            | 173              |
| Jun     | 22.2                             | 23.2      | 1014.7                          | 1015.5    | 118               | 80        | 130    | 27     | 0.5             | 246              | 1.0            | 199              |
| Jul     | 25.8                             | 26.0      | 1017.8                          | 1016.5    | 60                | 81        | 200    | 19     | 3.0             | 208              | 1.7            | 215              |
| Aug     | 25.4                             | 26.0      | 1015.2                          | 1016.5    | 121               | 105       | 221    | 30     | 2.0             | 176              | 0.5            | 98               |
| Sep     | 21.3                             | 22.2      | 1016.9                          | 1018.0    | 35                | 72        | 160    | 5      | 3.0             | 25               | 1.9            | 36               |
| Oct     | 15.1                             | 17.4      | 1017.1                          | 1019.8    | 69                | 64        | 143    | 17     | 2.3             | 352              | 2.5            | 27               |
| Nov     | 13.9                             | 13.3      | 1016.1                          | 1018.6    | 120               | 93        | 145    | 26     | 0.6             | 331              | 1.9            | 357              |
| Dec     | 6.4                              | 8.2       | 1020.0                          | 1019.8    | 16                | 62        | 131    | 4      | 2.2             | 301              | 2.1            | 335              |
| Average | 15.1                             | 15.7      | 1017.2                          | 1017.2    | 78                | 80        |        |        | 0.7             | 335              | 0.9            | 357              |
| Total   |                                  |           |                                 |           | 935               | 967       |        |        |                 |                  |                |                  |

### Air Temperature

11. The FRF enjoys a typical marine climate which moderates the temperature extremes of both summer and winter.



### Measurement instruments

12. A Yellow Springs Instrument Company, Inc. (YSI) (Yellow Springs, OH) electronic temperature probe with analog output interfaced to the FRF's computer was operated beside the NWS's meteorological instrument shelter located 43 m behind the dune (Figure 2). To ensure proper temperature readings, the probe was installed 3 m above ground inside a "coolie hat" to shade it from direct sun yet provide proper ventilation.

### Results

13. Daily and average air temperature values are tabulated in Table 2 and shown in Figure 3.

## Atmospheric Pressure

### Measurement instruments

14. Electronic atmospheric pressure sensor. Atmospheric pressure was measured with a YSI electronic sensor with analog output located in the laboratory building at 9 m above NGVD. Data were recorded on the FRF computer. Data from this gage were compared with those from an NWS aneroid barometer to ensure proper operation.

15. Microbarograph. A Weathertronics, Incorporated (Sacramento, CA) recording aneroid sensor (microbarograph) located in the laboratory building also was used to continuously record atmospheric pressure variation.

16. The microbarograph was compared daily with the NWS aneroid barometer, and adjustments were made as necessary. Maintenance of the microbarograph consisted of inking the pen, changing the chart paper, and winding the clock every 7 days. During the summer, a meteorologist from the NWS checked and verified the operation of the barometer.

17. The microbarograph was read and inspected daily using the following procedure:

- a. The pen was zeroed (where applicable).
- b. The chart time was checked and corrected, if necessary.
- c. Daily reading was marked on the chart for reference.
- d. The starting and ending chart times were recorded, as necessary.
- e. New charts were installed when needed.

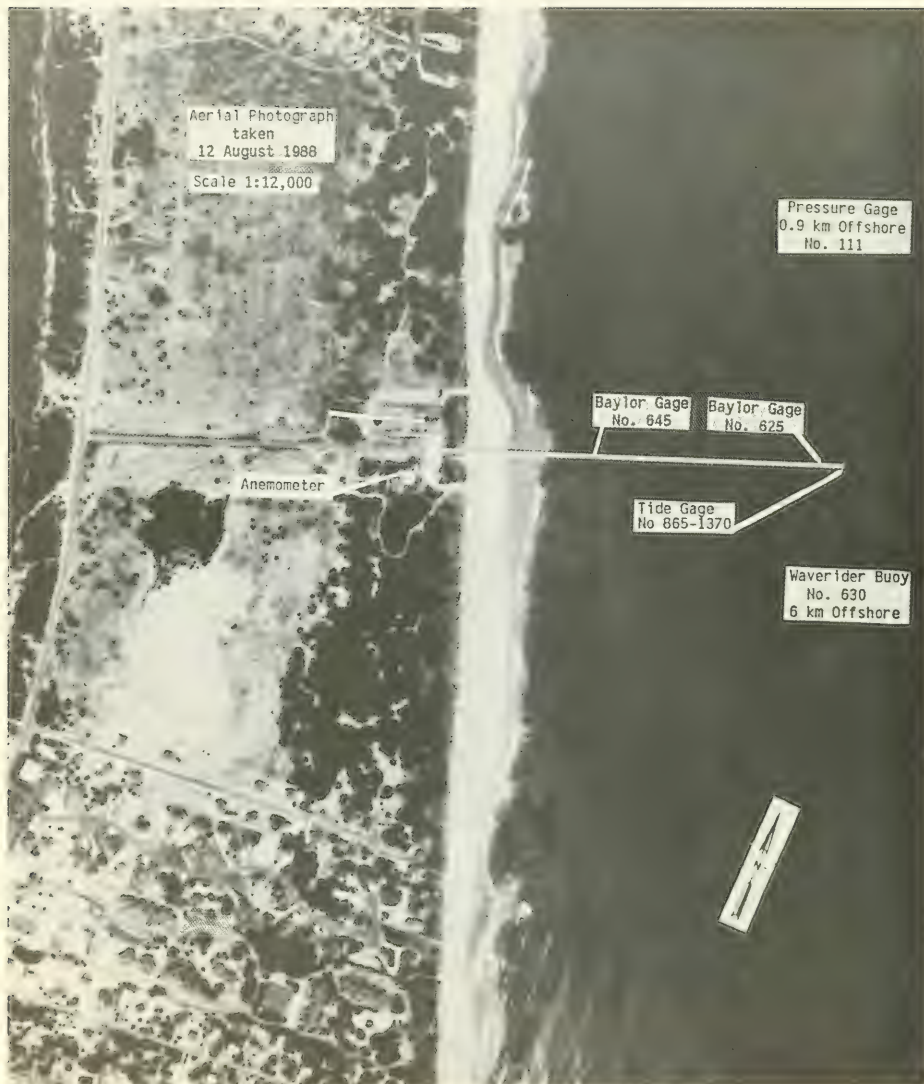


Figure 2. FRF gage locations

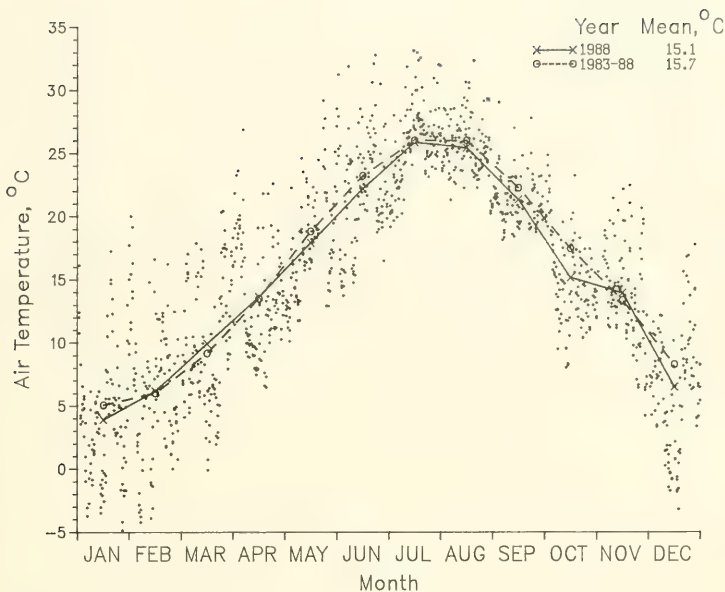


Figure 3. Daily air temperature values with monthly means

## Results

18. Daily and average atmospheric pressure values are presented in Figure 4, and summary statistics are presented in Table 2.

## Precipitation

19. Precipitation is generally well distributed throughout the year. Precipitation from midlatitude cyclones (northeasters) predominates in the winter, whereas local convection (thunderstorms) accounts for most of the summer rainfall.

## Measurement instruments

20. Electronic rain gage. A Belfort Instrument Company (Baltimore, MD) 30-cm weighing rain gage, located near the instrument shelter 47 m behind the dune, measured daily precipitation. According to the manufacturer, the

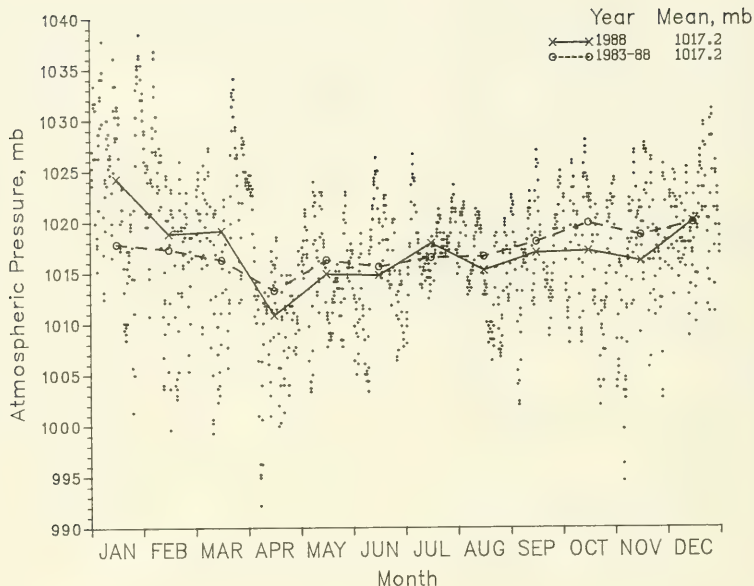


Figure 4. Daily barometric pressure values with monthly means

instrument's accuracy was 0.5 percent for precipitation amounts less than 15 cm and 1.0 percent for amounts greater than 15 cm.

21. The rain gage was inspected daily, and the analog chart recorder was maintained by procedures similar to those for the microbarograph.

22. Plastic rain gage. An Edwards Manufacturing Company (Alberta Lea, MN) True Check 15-cm-capacity clear plastic rain gage with a 0.025-cm resolution was used to monitor the performance of the weighing rain gage. This gage, located near the weighing gage, was compared daily; and very few discrepancies were identified during the year.

### Results

23. Daily and monthly average precipitation values are shown in Figure 5. Statistics of total precipitation for each month during this year and average totals for all years combined are presented in Table 2.



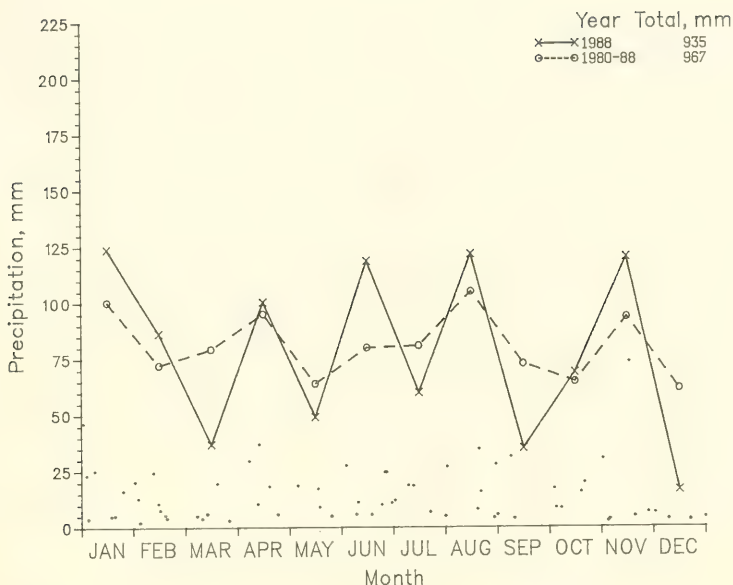


Figure 5. Daily precipitation values with monthly totals

### Wind Speed and Direction

24. Winds at the FRF are dominated by tropical maritime air masses which create low to moderate, warm southern breezes; arctic and polar air masses which produce cold winds from northerly directions; and smaller scale cyclonic, low pressure systems, which originate either in the tropics (and move north along the coast) or on land (and move eastward offshore). The dominant wind direction changes with season, being generally from northern directions in the fall and winter and from southern directions in the spring and summer. It is common for fall and winter storms (northeasters) to produce winds with average speeds in excess of 15 m/sec.

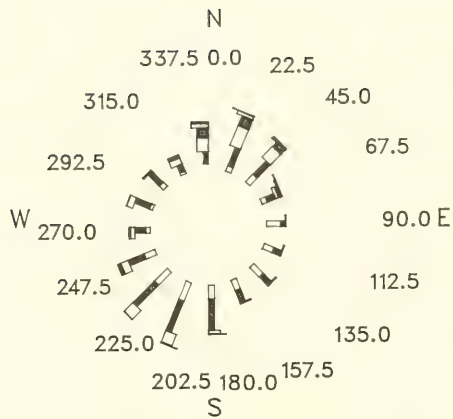
### Measurement instrument

25. Winds were measured on top of the laboratory building at an elevation of 19.1 m (Figure 2) using a Weather Measure Corporation (Sacramento, CA) Skyvane Model W102P anemometer. Wind speed and direction data were

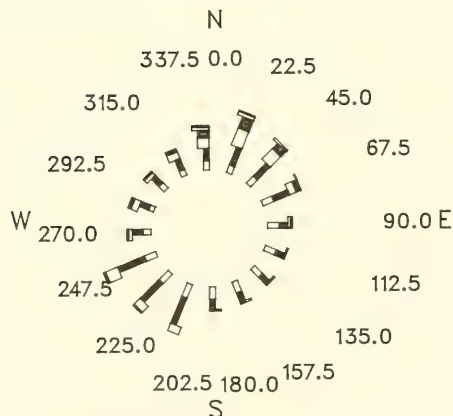
collected on the FRF computer as well as on a strip-chart recorder. The anemometer manufacturer specifies an accuracy of  $\pm 0.45$  m/sec below 13 m/sec and 3 percent at speeds above 13 m/sec, with a threshold of 0.9 m/sec. Wind direction accuracy is  $\pm 2$  deg with a resolution of less than 1 deg. The anemometer is calibrated annually at the National Bureau of Standards in Gaithersburg, MD, and is within the manufacturer's specifications.

### Results

26. Annual and monthly joint probability distributions of wind speed versus direction were computed. Winds speeds were resolved into 3-m/sec intervals, whereas the directions were at 22.5-deg intervals (i.e. 16-point compass direction specifications). These distributions are presented as wind "roses," such that the length of the petal represents the frequency of occurrence of wind blowing from the specified direction, and the width of the petal is indicative of the speed. Resultant directions and speeds were also determined by vector averaging the data (see Table 2). Wind statistics are presented in Figures 6, 7, and 8.



1988  
Speed 0.7 m/s  
Direction 335 deg



1980-1988  
Speed 0.9 m/s  
Direction 357 deg

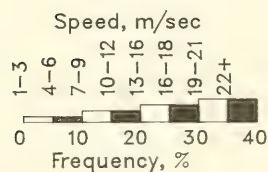


Figure 6. Annual wind roses

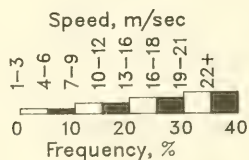
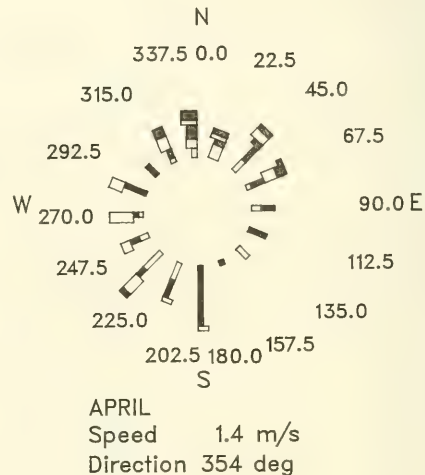
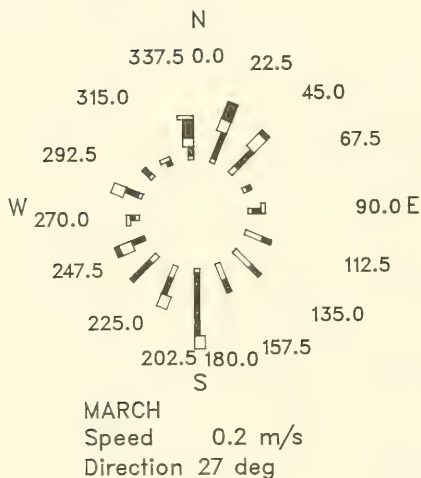
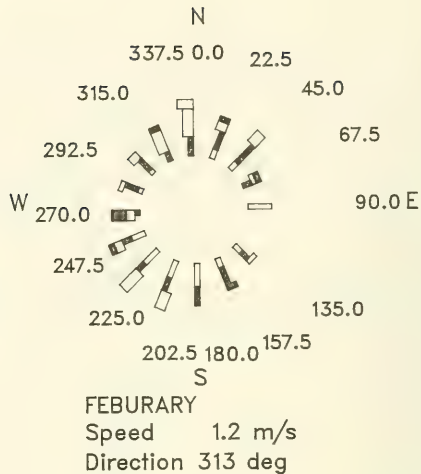
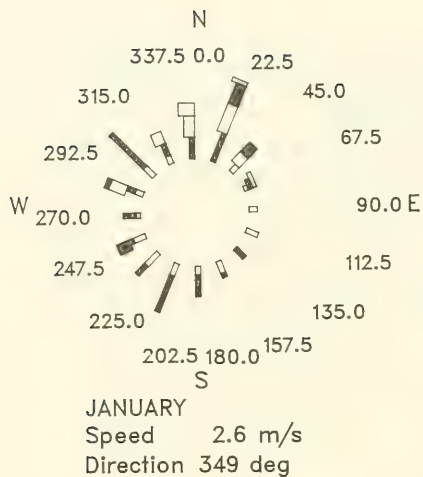
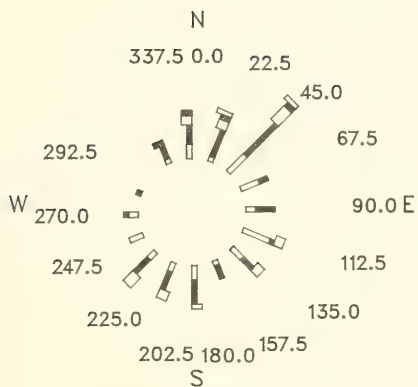
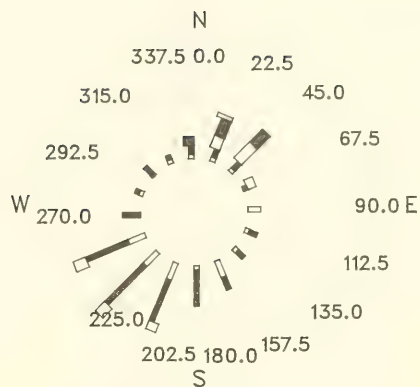


Figure 7. Monthly wind roses for 1988  
(Sheet 1 of 3)

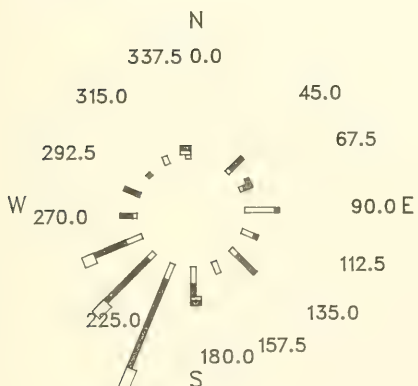




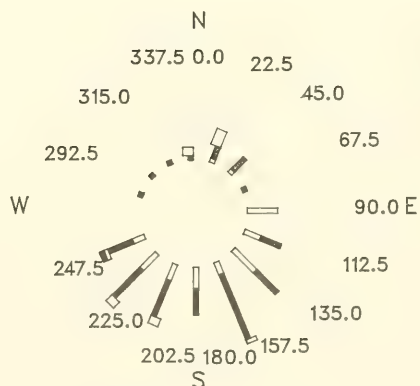
MAY  
Speed 1.5 m/s  
Direction 64 deg



JUNE  
Speed . 0.5 m/s  
Direction 246 deg



JULY  
Speed 3.0 m/s  
Direction 208 deg



AUGUST  
Speed 2.0 m/s  
Direction 176 deg

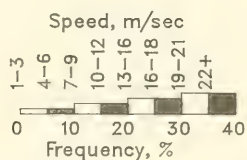


Figure 7. (Sheet 2 of 3)

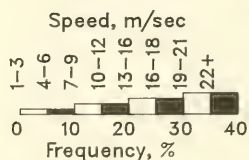
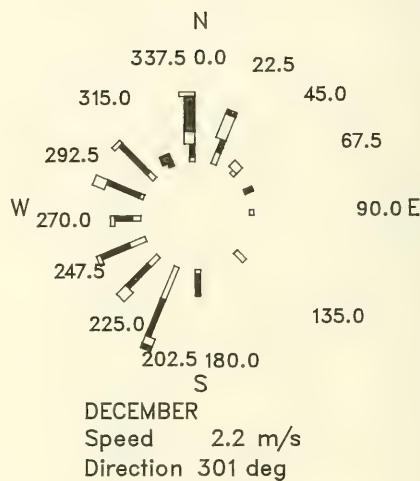
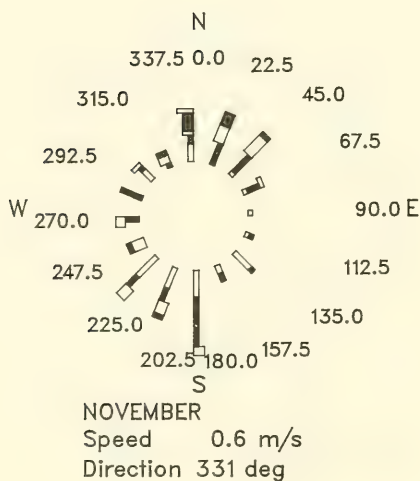
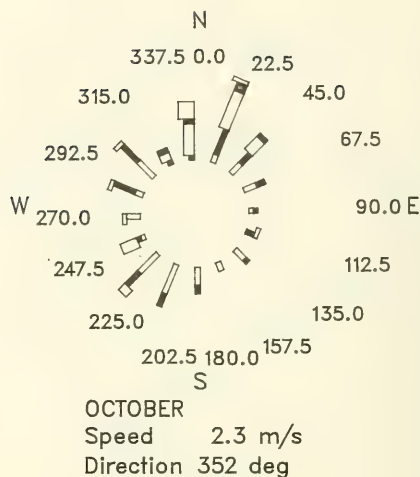
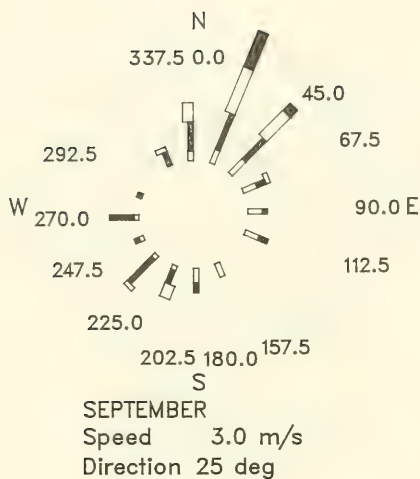


Figure 7. (Sheet 3 of 3)

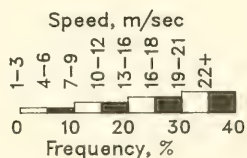
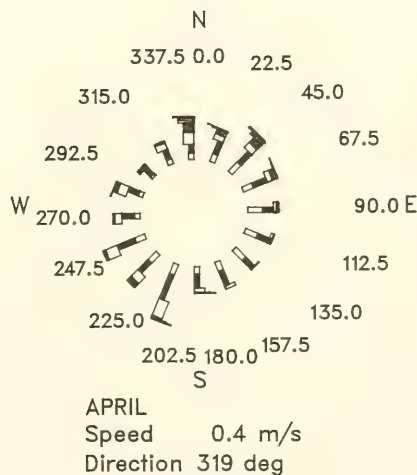
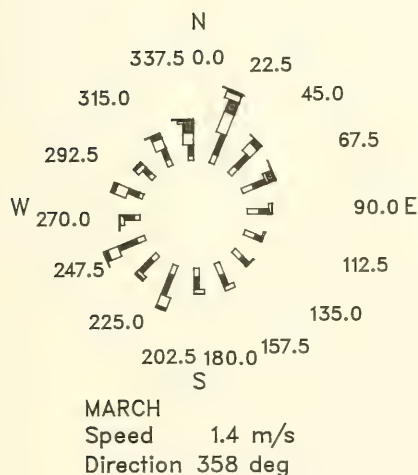
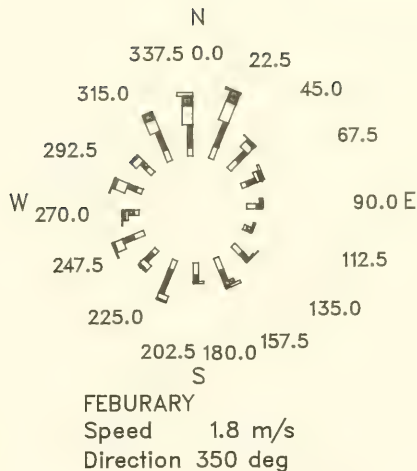
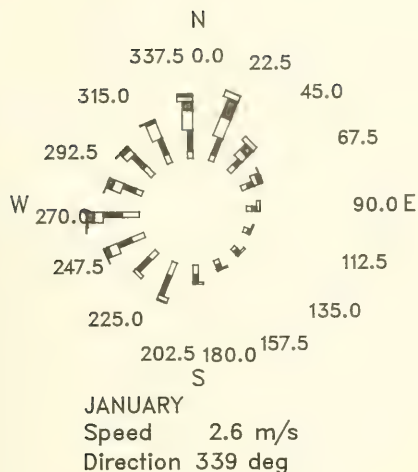


Figure 8. Monthly wind roses for 1980 through 1988 (Sheet 1 of 3)

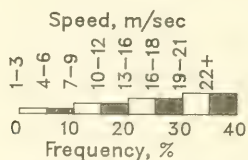
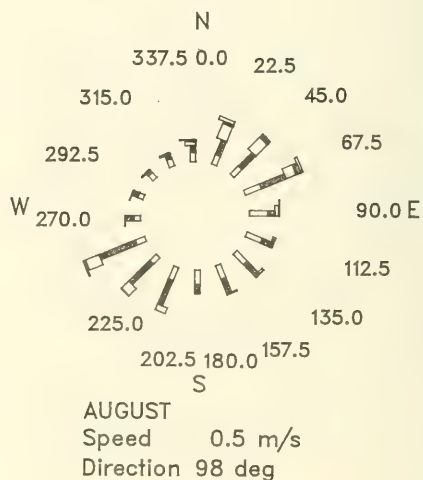
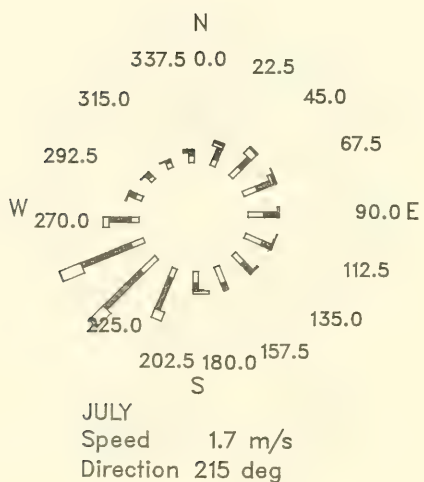
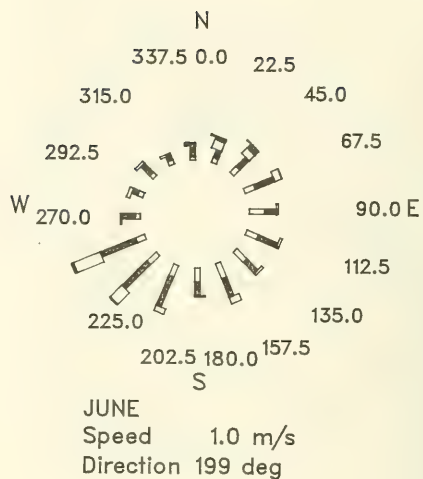
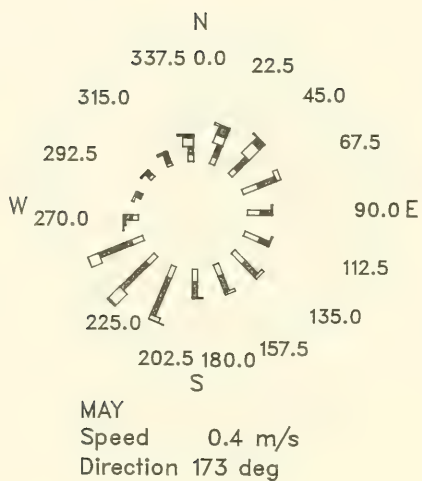


Figure 8. (Sheet 2 of 3)



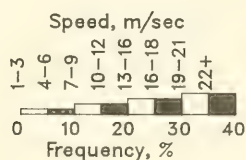
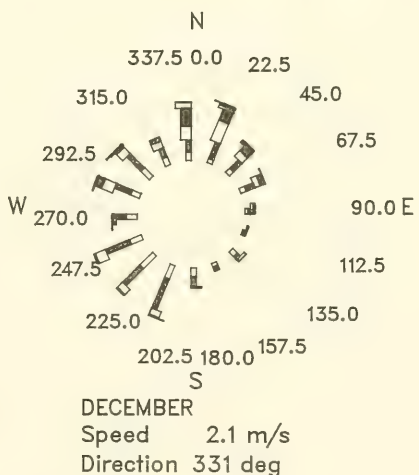
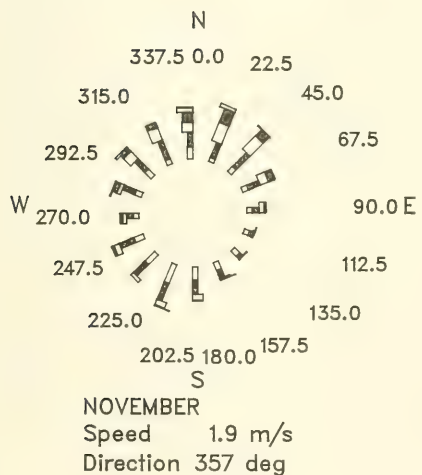
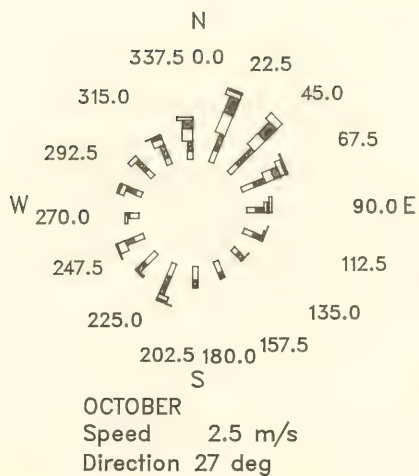
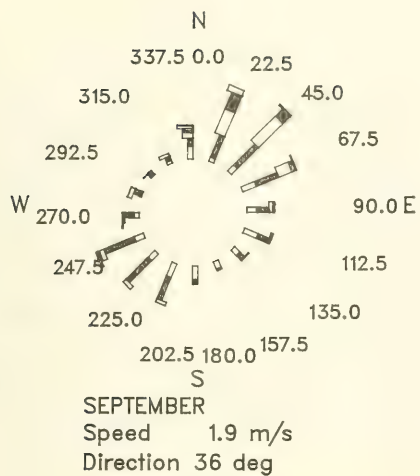


Figure 8. (Sheet 3 of 3)

### PART III: WAVES

27. This section presents summaries of the wave data. A discussion of individual major storms is given in Part IX and contains additional wave data for times when wave heights exceeded 2 m at the seaward end of the FRF pier. Appendixes B through E provide more extensive data summaries for each gage, including height and period distributions, wave direction distributions, persistence tables, and spectra during storms.

28. Wave directions (similar to wind directions) at the FRF are seasonally distributed. Waves approach most frequently from north of the pier in the fall and winter and south of the pier in the summer, with the exception of storm waves which approach twice as frequently from north of the pier. Annually, waves are approximately evenly distributed between north and south (resultant wave direction being almost shore-normal).

#### Measurement Instruments

29. The wave gages included two wave staff gages (Gages 645 and 625), one buoy (Gage 630), and one pressure (Gage 111) as shown in Figure 2 and located as follows:

| <u>Gage Type/Number</u>  | <u>Distance Offshore<br/>from Baseline</u> | <u>Water Depth<br/>m</u> | <u>Operational<br/>Period</u> |
|--------------------------|--|--------------------------|-------------------------------|
| Continuous wire (645)    | 238 m                                      | 3.5                      | 11/84-12/88                   |
| Continuous wire (625)    | 579 m                                      | 8                        | 11/78-12/88                   |
| Accelerometer buoy (630) | 6 km                                       | 18                       | 11/78-12/88                   |
| Pressure gage (111)      | 1 km                                       | 9                        | 09/86-12/88                   |

#### Staff gages

30. Two Baylor Company (Houston, TX) parallel cable inductance wave gages (Gage 645 at sta 7+80 and Gage 625 at sta 19+00 (Figure 2)) were mounted on the FRF pier. Rugged and reliable, these gages require little maintenance except to keep tension on the cables and to remove any material which may cause an electrical short between them. They were calibrated prior to installation by creating an electrical short between the two cables at known distances along the cable and recording the voltage output. Electronic signal conditioning amplifiers are used to ensure that the output signals from the gages are within a 0- to 5-V range. Manufacturer-stated gage accuracy is about 1.0 percent, with a 0.1-percent full-scale resolution; full scale is 14 m for Gage 625 and 8.2 m for Gage 645. These gages are susceptible to

lightning damage, but protective measures have been taken to minimize such occurrences. A more complete description of the gages' operational characteristics was given by Grogg (1986).

#### Buoy gage

31. One Datawell Laboratory for Instrumentation (Haarlem, The Netherlands) Waverider buoy gage (Gage 630) measures the vertical acceleration produced by the passage of a wave. The acceleration signal is double-integrated to produce a displacement signal which is transmitted by radio to an onshore receiver. The manufacturer stated that wave amplitudes are correct to within 3 percent of their actual value for wave frequencies between 0.065 and 0.500 Hz (corresponding 15- to 2-sec wave periods). The manufacturer also specified that the error gradually increased to 10 percent for wave periods in excess of 20 sec. The results in this report were not corrected for the manufacturer's specified amplitude errors. However, the buoy was calibrated semiannually to ensure that it was within the manufacturer's specification.

#### Pressure gage

32. One Senso-Metrics, Incorporated (Simi Valley, CA), pressure transduction gage (Gage 111) installed near the ocean bottom measures the pressure changes produced by the passage of waves creating an output signal which is linear and proportional to pressure when operated within its design limits. Predeployment and postdeployment precision calibrations are performed at the FRF using a static deadweight tester. The sensor's range is 0 to 25 psi (equivalent to 0- to 17-m seawater) above atmospheric pressure with a manufacturer-stated accuracy of  $\pm 0.25$  percent. Copper scouring pads are installed at the sensor's diaphragm to reduce biological fouling, and the system is periodically cleaned by divers.

### Digital Data Analysis and Summarization

33. The data were collected, analyzed, and stored on magnetic tape using the FRF's VAX computer. Data sets were normally collected every 6 hr. During storms, the collection was at 3-hr intervals. For each gage a data set consisted of 4 contiguous records of 4,096 points recorded at 0.5 Hz (approximately 34-min long), for a total of 2 hr and 16 min. Analysis was performed on individual 34-min records.

34. The analysis program computes the first moment (mean) and the

second moment about the mean (variance) and then edits the data by checking for "jumps," "spikes," and points exceeding the voltage limit of the gage. A jump is defined as a data value greater than five standard deviations from the previous data value, whereas a spike is a data value more than five standard deviations from the mean. If less than five consecutive jumps or spikes are found, the program linearly interpolates between acceptable data and replaces the erroneous data values. The editing stops if the program finds more than five consecutive jumps or spikes or more than a total of 100 bad points or the variance of the voltage is below  $1 \times 10^{-5}$  squared volts. The statistics and diagnostics from the analysis are saved.

35. Sea surface energy spectra are computed from the edited time series. Spectral estimates are computed from smaller data segments obtained by dividing the 4,096-point record into several 512-point segments. The estimates are then ensemble-averaged to produce a more accurate spectrum. These data segments are overlapped by 50 percent (known as the Welch (1967) method) and have been shown to produce improved statistical properties than from nonoverlapped segments. The mean and linear trends are removed from each segment prior to spectral analysis. To reduce sidelobe leakage in the spectral estimates, a data window was applied. The first and last 10 percent of data points was multiplied by a cosine bell (Bingham, Godfrey, and Tukey 1967). Spectra were computed from each segment with a discreet Fast Fourier Transform and then ensemble-averaged. Sea surface spectra from subsurface pressure gages were obtained by applying the linear wave theory transfer function.

36. Unless otherwise stated, wave height in this report refers to the energy-based parameter  $H_m$  defined as four times the zeroth moment wave height of the estimated sea surface spectrum (i.e., four times the square root of the variance) computed from the spectrum passband. Energy computations from the spectra are limited to a passband between 0.05 and 0.50 Hz for surface gages and between 0.05 Hz and a high frequency cutoff for subsurface gages. This high frequency limit is imposed to eliminate aliased energy and noise measurements from biasing the computation of  $H_m$  and is defined as the frequency where the linear theory transfer function is less than 0.1 (spectral values are multiplied by 100 or more). Smoother and more statistically significant spectral estimates are obtained by band-averaging contiguous spectral components (three components are averaged per band producing a

frequency band width of 0.0117 Hz).

37. Wave period  $T_p$  is defined as the period associated with the maximum energy band in the spectrum which is computed using a 3-point running average band on the spectrum. The peak period is reported as the reciprocal of the center frequency (i.e.,  $T_p = 1/\text{frequency}$ ) of the spectral band with the highest energy. A detailed description of the analysis techniques is presented in a report by Andrews (1987).\*

### Results

38. The wave conditions for the year are shown in Figure 9. For all four gages, the distributions of wave height for the current year and all years combined are presented in Figures 10 and 11, respectively. Distributions of wave period are presented in Figure 12.

39. Multiple year comparisons of data for Gage 111 actually incorporate data for 1985 and 1986 from Gage 640, a discontinued Waverider buoy previously located at the approximate depth and distance offshore as Gage 111 and data for 1987 from Gage 141, located 30 m south of Gage 111.

40. Refraction, bottom friction, and wave breaking contribute to the observed differences in height and period. During the most severe storms when the wave heights exceed 3 m at the seaward end of the pier, the surf zone (wave breaking) has been observed to extend past the end of the pier and occasionally 1 km offshore. This occurrence is a major reason for the differences in the distributions between Gage 630 and the inshore gages. The wave height statistics for the staff gage (Gage 645), located at the landward end of the pier, were considerably lower than those for the other gages. In all but the calmest conditions, this gage is within the breaker zone. Consequently, these statistics represent a lower energy wave climate.

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\* M. E. Andrews. 1987. "Standard Wave Data Analysis Procedures for Coastal Engineering Applications," unpublished report prepared for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.



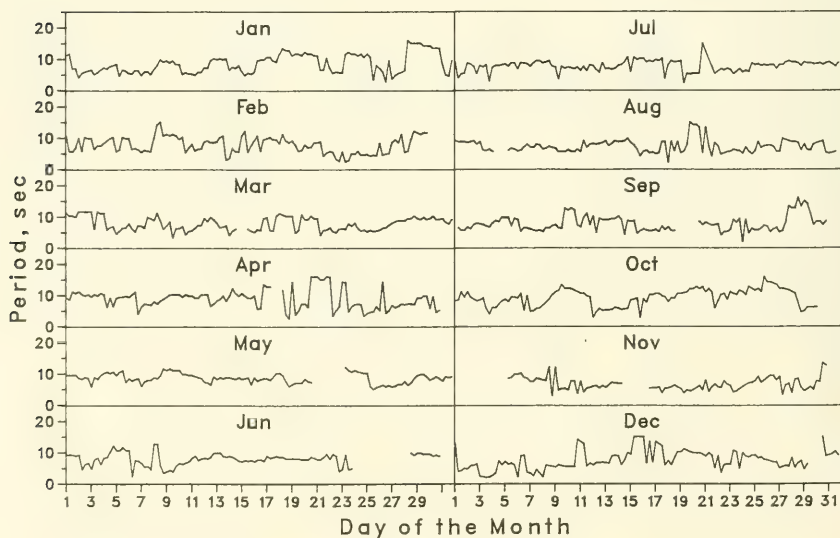
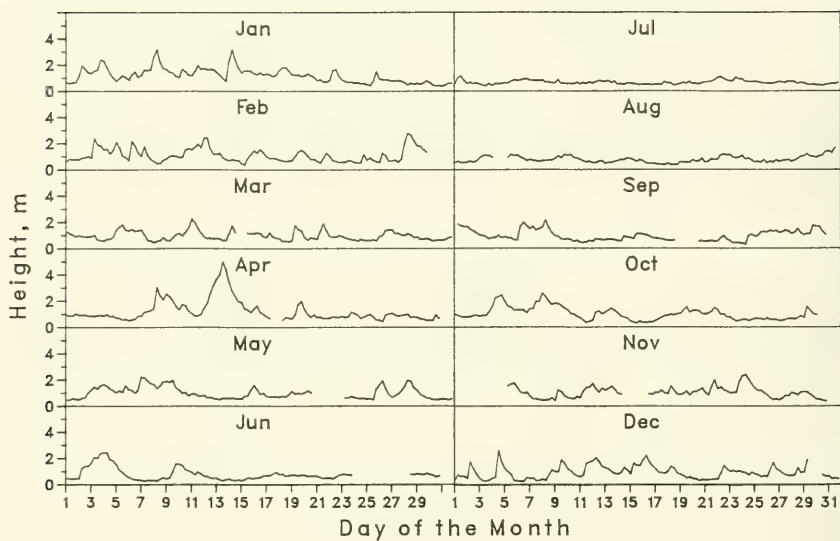


Figure 9. Time-histories of wave height and period for Gage 630

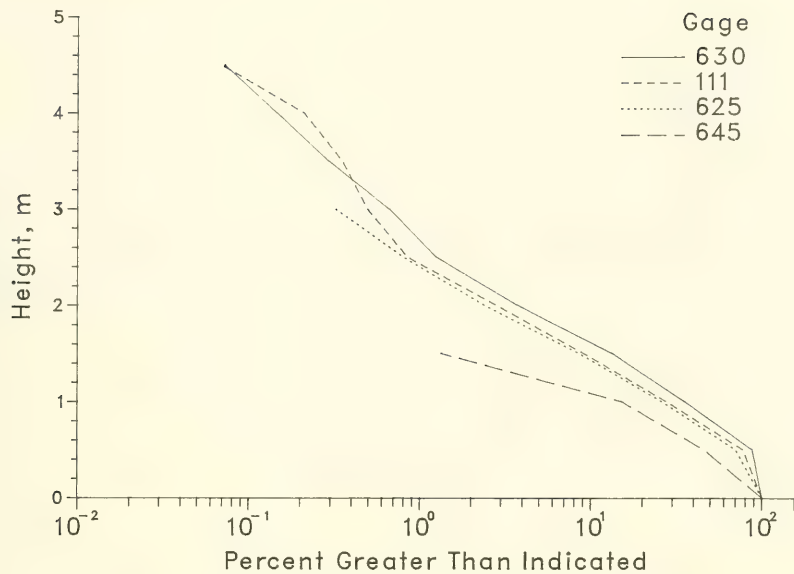


Figure 10. 1988 annual wave height distributions

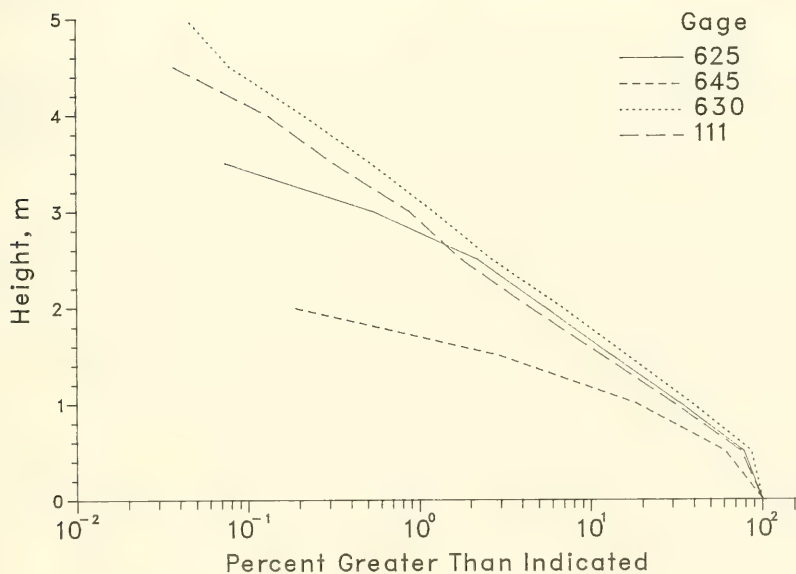


Figure 11. Annual distribution of wave heights  
for 1980 through 1988

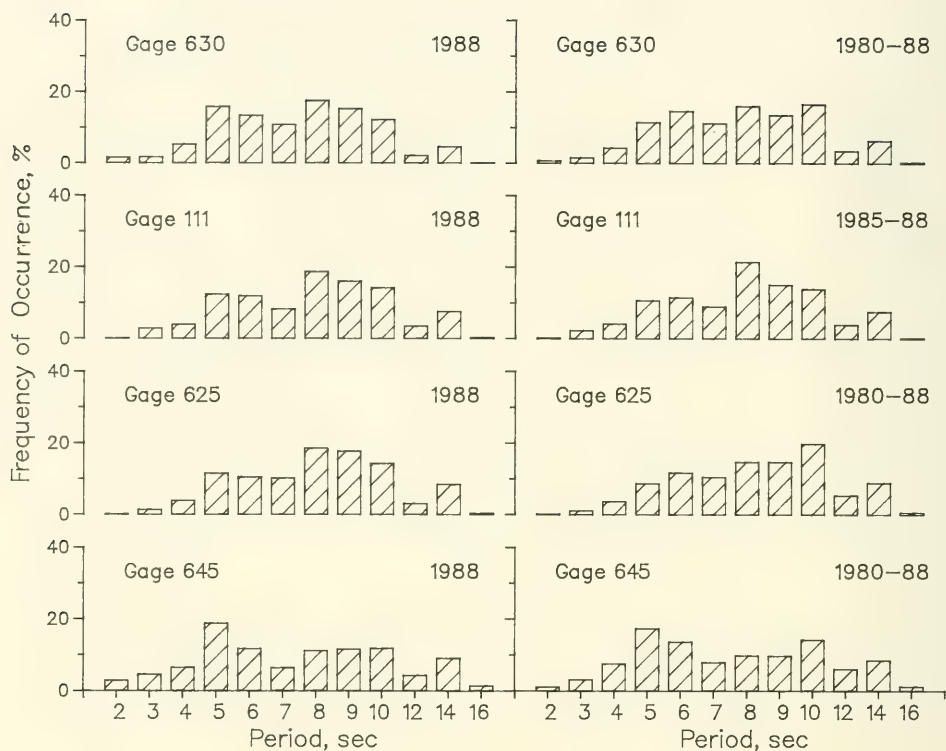


Figure 12. Annual wave period distributions for all gages

41. Summary wave statistics for the current year and all years combined are presented for Gage 630 in Table 3.

Table 3  
Wave Statistics for Gage 630

| Month  | 1988   |      |         |        |      |      |        | 1980-1988 |      |         |          |      |      |        |
|--------|--------|------|---------|--------|------|------|--------|-----------|------|---------|----------|------|------|--------|
|        | Height |      |         | Period |      |      |        | Height    |      |         | Period   |      |      |        |
|        | Std.   |      |         | Std.   |      |      |        | Std.      |      |         | Std.     |      |      |        |
|        | Mean   | Dev. | Extreme | Date   | Mean | Dev. | Number | Mean      | Dev. | Extreme | Date     | Mean | Dev. | Number |
|        | m      | m    | m       |        | sec  | sec  | Obs.   | m         | m    | m       |          | sec  | sec  | Obs.   |
| Jan    | 1.2    | 0.6  | 3.1     | 8      | 8.5  | 3.1  | 124    | 1.2       | 0.7  | 4.5     | 1983     | 8.0  | 2.8  | 950    |
| Feb    | 1.1    | 0.6  | 2.7     | 28     | 7.8  | 2.6  | 116    | 1.2       | 0.7  | 5.1     | 1987     | 8.5  | 2.6  | 905    |
| Mar    | 1.0    | 0.4  | 2.2     | 11     | 7.8  | 2.2  | 121    | 1.2       | 0.7  | 4.7     | 1983     | 8.6  | 2.7  | 998    |
| Apr    | 1.3    | 0.9  | 5.2     | 13     | 8.9  | 3.1  | 116    | 1.1       | 0.7  | 5.2     | 1988     | 8.7  | 2.8  | 975    |
| May    | 1.0    | 0.5  | 2.2     | 7      | 8.6  | 1.6  | 111    | 0.9       | 0.5  | 3.3     | 1986     | 8.1  | 2.3  | 983    |
| Jun    | 0.8    | 0.5  | 2.4     | 4      | 8.0  | 2.0  | 101    | 0.8       | 0.4  | 2.4     | 1988     | 7.7  | 2.2  | 927    |
| Jul    | 0.7    | 0.2  | 1.1     | 1      | 7.9  | 1.7  | 121    | 0.7       | 0.3  | 2.1     | 1985     | 8.1  | 2.5  | 948    |
| Aug    | 0.8    | 0.3  | 1.6     | 31     | 7.4  | 2.1  | 119    | 0.8       | 0.5  | 3.6     | 1981     | 7.9  | 2.4  | 949    |
| Sep    | 1.0    | 0.5  | 2.1     | 8      | 7.8  | 2.5  | 111    | 1.0       | 0.6  | 6.1     | 1985     | 8.5  | 2.6  | 960    |
| Oct    | 1.0    | 0.5  | 2.6     | 8      | 9.3  | 2.7  | 108    | 1.2       | 0.7  | 4.3     | 1982     | 8.7  | 2.8  | 1039   |
| Nov    | 1.1    | 0.5  | 2.4     | 24     | 6.8  | 2.1  | 94     | 1.2       | 0.7  | 4.1     | 1981     | 7.9  | 2.8  | 861    |
| Dec    | 1.0    | 0.5  | 2.6     | 4      | 7.6  | 3.2  | 118    | 1.1       | 0.7  | 5.6     | 1980     | 8.3  | 3.0  | 887    |
| Annual | 1.0    | 0.6  | 5.2     | Apr    | 8.0  | 2.6  | 1360   | 1.0       | 0.6  | 6.1     | Sep 1985 | 8.3  | 2.6  | 11382  |

42. Annual joint distributions of wave height versus wave period for Gage 630 are presented for 1988 in Table 4, and for all years combined in Table 5. Similar distributions for the other gages are included in Appendixes B-E.

43. Annual distributions of wave directions (relative to True North) based on daily observations of direction at the seaward end of the pier and height from Gage 625 (or Gage 111 when data for Gage 625 were unavailable) are shown in Figure 13. Monthly wave "roses" for 1988 and all years combined are presented in Figures 14 and 15, respectively.

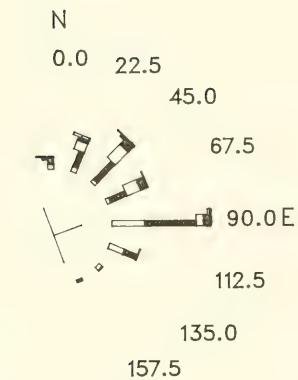
Table 4  
Annual Joint Distribution of  $H_{m0}$  versus  $T_p$  for Gage 630

| Annual 1988<br>Percent Occurrence(X100) of Height and Period |             |            |            |            |            |            |            |            |             |             |             |               |       |
|--|-------------|------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|---------------|-------|
| Height(m)  | Period(sec) |            |            |            |            |            |            |            |             |             |             |               | Total |
|  | 2.0-        | 3.0-       | 4.0-       | 5.0-       | 6.0-       | 7.0-       | 8.0-       | 9.0-       | 10.0-       | 12.0-       | 14.0-       | 16.0-         |       |
|  | <u>2.9</u>  | <u>3.9</u> | <u>4.9</u> | <u>5.9</u> | <u>6.9</u> | <u>7.9</u> | <u>8.9</u> | <u>9.9</u> | <u>11.9</u> | <u>13.9</u> | <u>15.9</u> | <u>Longer</u> |       |
| 0.00 - 0.49  | 88          | 22         | 22         | 103        | 22         | 96         | 301        | 301        | 103         | 44          | 103         | .             | 1205  |
| 0.50 - 0.99  | 66          | 147        | 301        | 662        | 551        | 610        | 1051       | 904        | 662         | 118         | 191         | .             | 5263  |
| 1.00 - 1.49  | .           | .          | 184        | 515        | 456        | 221        | 206        | 199        | 272         | 29          | 118         | .             | 2200  |
| 1.50 - 1.99  | .           | .          | 22         | 265        | 199        | 74         | 110        | 74         | 154         | 22          | 37          | .             | 957   |
| 2.00 - 2.49  | .           | .          | .          | 29         | 81         | 44         | 51         | 15         | 22          | .           | 7           | .             | 249   |
| 2.50 - 2.99  | .           | .          | .          | 7          | 22         | 7          | .          | 15         | .           | .           | 7           | .             | 58    |
| 3.00 - 3.49  | .           | .          | .          | .          | .          | 22         | 7          | 7          | .           | .           | .           | .             | 36    |
| 3.50 - 3.99  | .           | .          | .          | .          | .          | .          | 15         | .          | .           | .           | .           | .             | 15    |
| 4.00 - 4.49  | .           | .          | .          | .          | .          | .          | 7          | .          | .           | .           | .           | .             | 7     |
| 4.50 - 4.99  | .           | .          | .          | .          | .          | .          | .          | 7          | .           | .           | .           | .             | 7     |
| 5.00 - Greater   | .           | .          | .          | .          | .          | .          | .          | .          | .           | .           | .           | .             | 0     |
| Total  | 154         | 169        | 529        | 1581       | 1331       | 1074       | 1748       | 1522       | 1213        | 213         | 463         | 0             |       |

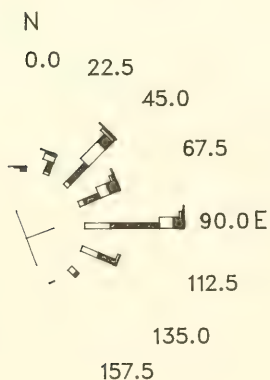
Table 5  
Annual Joint Distribution of  $H_{m0}$  versus  $T_p$  for Gage 630 (All Years)

| Annual 1980-1988<br>Percent Occurrence(X100) of Height and Period |             |            |            |            |            |            |            |            |             |             |             |               |       |
|---|-------------|------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|---------------|-------|
| Height(m)   | Period(sec) |            |            |            |            |            |            |            |             |             |             |               | Total |
|   | 2.0-        | 3.0-       | 4.0-       | 5.0-       | 6.0-       | 7.0-       | 8.0-       | 9.0-       | 10.0-       | 12.0-       | 14.0-       | 16.0-         |       |
|   | <u>2.9</u>  | <u>3.9</u> | <u>4.9</u> | <u>5.9</u> | <u>6.9</u> | <u>7.9</u> | <u>8.9</u> | <u>9.9</u> | <u>11.9</u> | <u>13.9</u> | <u>15.9</u> | <u>Longer</u> |       |
| 0.00 - 0.49   | 28          | 18         | 28         | 62         | 94         | 115        | 328        | 281        | 200         | 76          | 134         | 4             | 1368  |
| 0.50 - 0.99   | 39          | 128        | 254        | 499        | 572        | 515        | 860        | 717        | 812         | 151         | 213         | 15            | 4775  |
| 1.00 - 1.49   | .           | 10         | 134        | 402        | 451        | 264        | 246        | 200        | 360         | 39          | 132         | 4             | 2242  |
| 1.50 - 1.99   | .           | .          | 13         | 156        | 256        | 109        | 79         | 70         | 139         | 35          | 77          | 4             | 938   |
| 2.00 - 2.49   | .           | .          | 2          | 26         | 78         | 74         | 49         | 41         | 70          | 29          | 41          | 2             | 412   |
| 2.50 - 2.99   | .           | .          | .          | 1          | 9          | 32         | 17         | 16         | 38          | 11          | 23          | .             | 147   |
| 3.00 - 3.49   | .           | .          | .          | .          | 1          | 9          | 15         | 14         | 17          | 4           | 9           | .             | 69    |
| 3.50 - 3.99   | .           | .          | .          | .          | .          | 1          | 5          | 7          | 10          | 4           | 4           | .             | 31    |
| 4.00 - 4.49   | .           | .          | .          | .          | .          | .          | 2          | 2          | 7           | 1           | 2           | .             | 14    |
| 4.50 - 4.99   | .           | .          | .          | .          | .          | .          | .          | 1          | 3           | .           | .           | .             | 4     |
| 5.00 - Greater  | .           | .          | .          | .          | .          | .          | 1          | .          | .           | 2           | 1           | .             | 4     |
| Total   | 67          | 156        | 431        | 1146       | 1461       | 1119       | 1602       | 1349       | 1656        | 352         | 636         | 29            |       |





S  
1988  
Height 0.7 m  
Direction 59 deg



S  
1980-1988  
Height 0.8 m  
Direction 66 deg

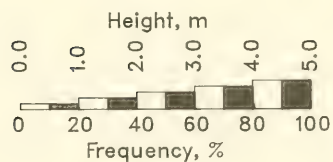


Figure 13. Annual wave roses

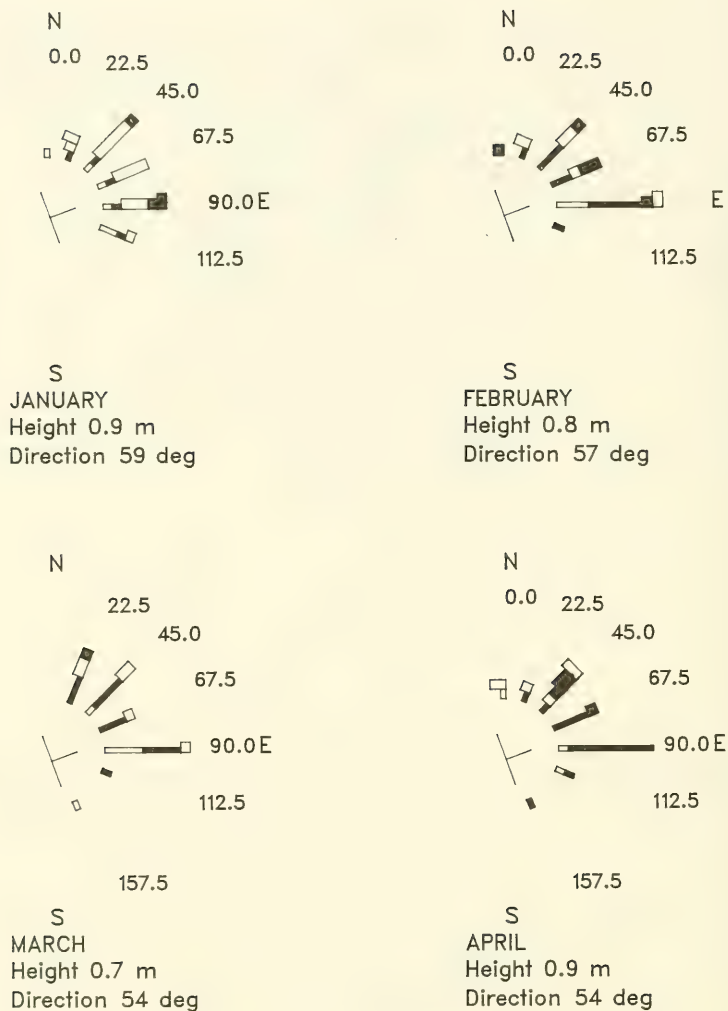


Figure 14. Monthly wave roses for 1988 (Sheet 1 of 3)

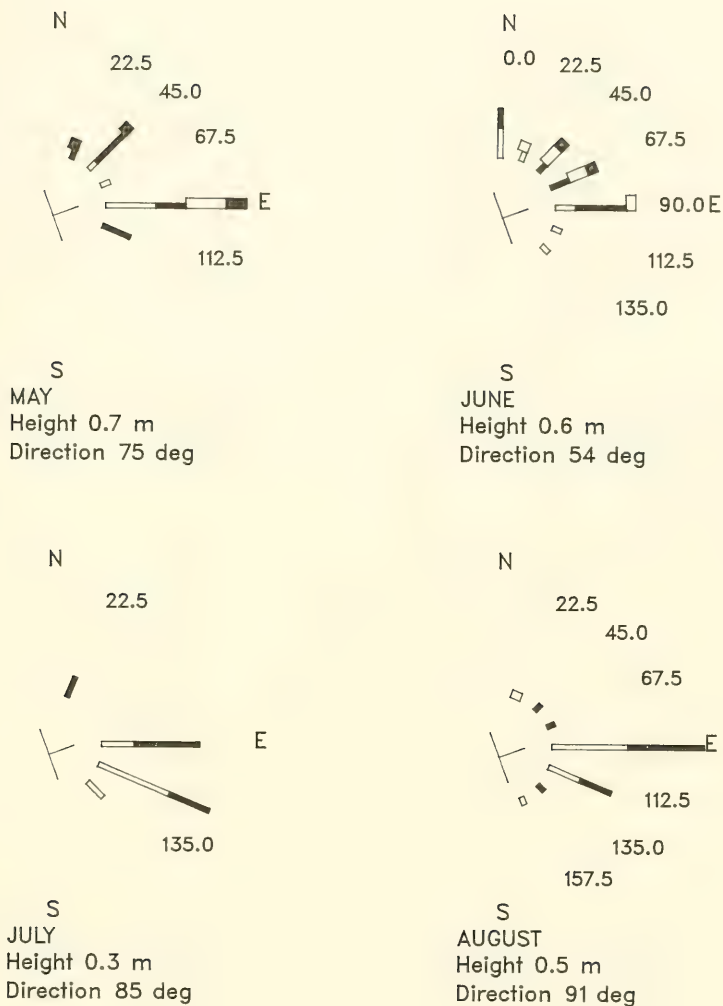
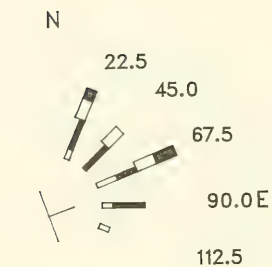
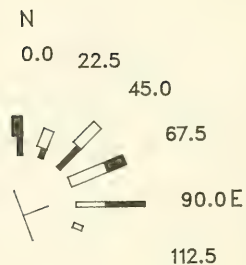


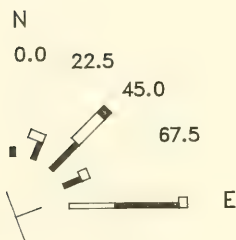
Figure 14. (Sheet 2 of 3)



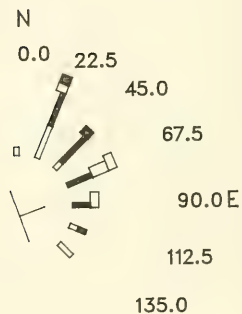
S  
SEPTEMBER  
Height 0.8 m  
Direction 50 deg



S  
OCTOBER  
Height 0.8 m  
Direction 48 deg



S  
NOVEMBER  
Height 0.8 m  
Direction 55 deg



S  
DECEMBER  
Height 0.7 m  
Direction 54 deg

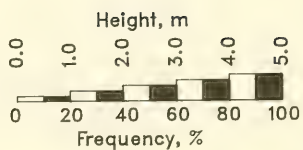
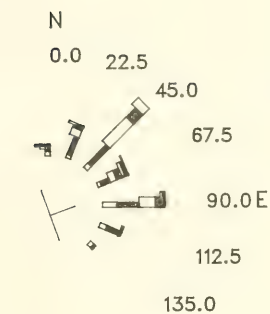
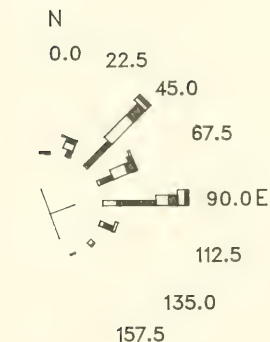


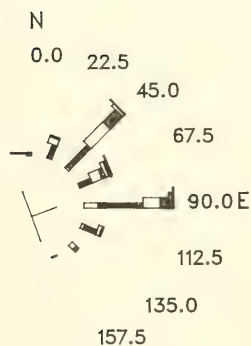
Figure 14. (Sheet 3 of 3)



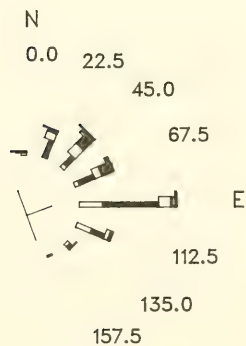
S  
JANUARY  
Height 0.9 m  
Direction 57 deg



S  
FEBRUARY  
Height 1.0 m  
Direction 63 deg



S  
MARCH  
Height 0.9 m  
Direction 66 deg



S  
APRIL  
Height 0.8 m  
Direction 67 deg

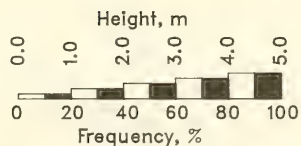


Figure 15. Monthly wave roses for 1980 through 1988  
(Sheet 1 of 3)



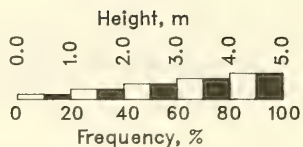
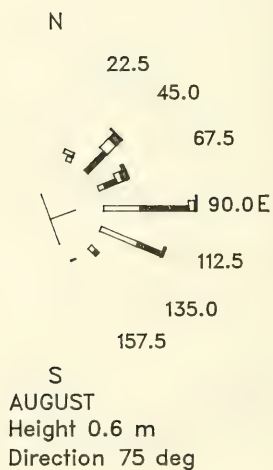
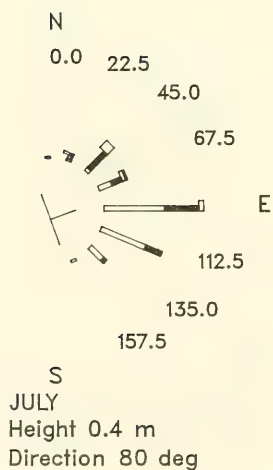
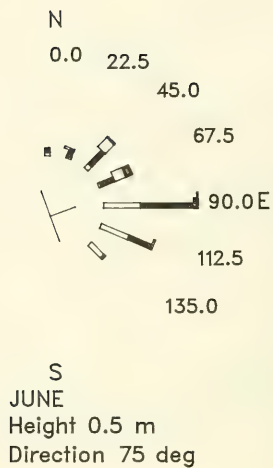
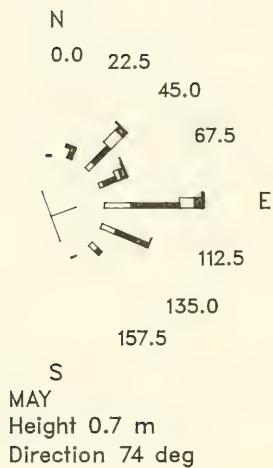
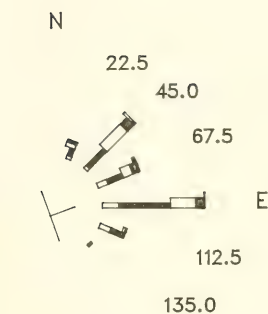
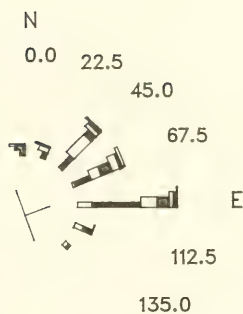


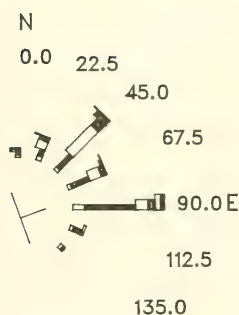
Figure 15. (Sheet 2 of 3)



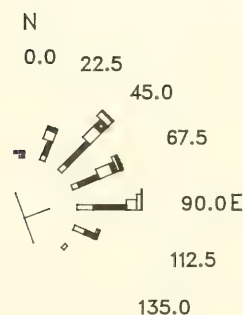
S  
SEPTEMBER  
Height 0.8 m  
Direction 67 deg



S  
OCTOBER  
Height 1.0 m  
Direction 66 deg



S  
NOVEMBER  
Height 0.9 m  
Direction 61 deg



S  
DECEMBER  
Height 0.8 m  
Direction 59 deg

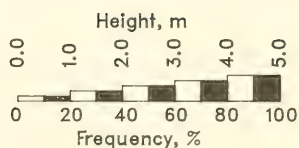


Figure 15 (Sheet 3 of 3)

## PART IV: CURRENTS

44. Surface current speed and direction at the FRF are influenced by winds, waves, and, indirectly, by the bottom topography. The extent of the respective influence varies daily. However, winds tend to dominate the currents at the seaward end of the pier, whereas waves dominate within the surf zone.

### Observations

45. Near 0700 EST, daily observations of surface current speed and direction were made at (a) the seaward end of the pier, (b) the midsurf position on the pier, and (c) 10 to 15 m from the beach 500 m updrift of the pier. Surface currents were determined by observing the movement of dye on the water surface.

### Results

46. Annual mean and mean currents for 1980 through 1988 are presented in Table 6 and in Figure 16. Figure 16 shows the daily and average annual measurements at the beach, pier midsurf, and pier end locations. Since the relative influences of the winds and waves vary with position from shore, the current speeds and, to some extent, direction vary at the beach, midsurf, and pier end locations. Magnitudes generally are largest at the midsurf location and lowest at the end of the pier.

Table 6  
Mean Longshore Surface Currents\*

| <u>Month</u> | <u>Pier End, cm/sec</u> |                       | <u>Pier Midsurf, cm/sec</u> |                       | <u>Beach, cm/sec</u> |                       |
|--------------|-------------------------|-----------------------|-----------------------------|-----------------------|----------------------|-----------------------|
|              | <u>1988</u>             | <u>1980-<br/>1988</u> | <u>1988</u>                 | <u>1980-<br/>1988</u> | <u>1988</u>          | <u>1980-<br/>1988</u> |
| Jan          | 7                       | 16                    | 10                          | 20                    | 4                    | 13                    |
| Feb          | 15                      | 18                    | 3                           | 11                    | 15                   | 12                    |
| Mar          | 14                      | 16                    | 3                           | 14                    | 33                   | 14                    |
| Apr          | 8                       | 11                    | -12                         | 1                     | 6                    | 8                     |
| May          | 21                      | 11                    | 14                          | -4                    | -3                   | -1                    |
| Jun          | 4                       | 5                     | -15                         | -8                    | -10                  | -5                    |
| Jul          | 10                      | 3                     | 12                          | -16                   | 0                    | -9                    |
| Aug          | -10                     | 8                     | -31                         | -12                   | -28                  | -5                    |
| Sep          | 4                       | 7                     | -26                         | -6                    | -30                  | -1                    |
| Oct          | 18                      | 9                     | -1                          | 0                     | 5                    | 2                     |
| Nov          | 13                      | 14                    | 16                          | 8                     | 7                    | 11                    |
| Dec          | -1                      | 14                    | -13                         | 14                    | 7                    | 8                     |
| Annual       | 9                       | 11                    | -3                          | 2                     | 1                    | 4                     |

---

\* + = southward; - = northward.

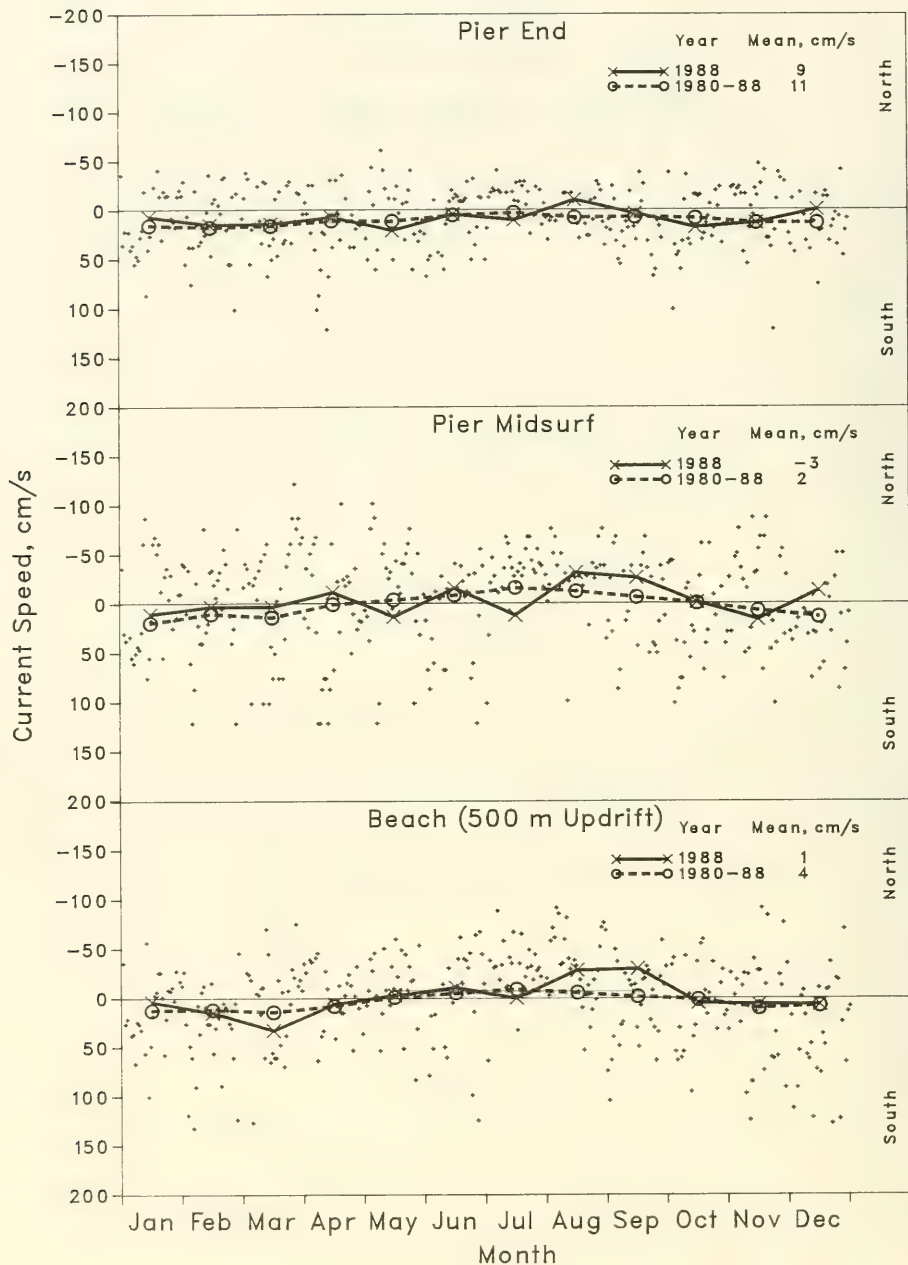


Figure 16. Daily current speeds and directions with monthly means for 1988



## PART V: TIDES AND WATER LEVELS

### Measurement Instrument

47. Water level data were obtained from a NOAA/NOS control tide station (sta 865-1370) located at the seaward end of the research pier (Figure 2) by using a Leupold and Stevens, Inc. (Beaverton, OR) digital tide gage. This analog-to-digital recorder is a float-activated, negator-spring, counterpoised instrument that mechanically converts the vertical motion of a float into a coded, punched paper tape record. The below-deck installation at pier sta 19+60 consisted of a 30.5-cm-diam stilling well with a 2.5-cm orifice and a 21.6-cm-diam float.

48. Operation and tending of the tide gage conformed to NOS standards. The gage was checked daily for proper operation of the punch mechanism and for accuracy of the time and water level information. The accuracy was determined by comparing the gage level reading with a level read from a reference electric tape gage. Once a week, a heavy metal rod was lowered down the stilling well and through the orifice to ensure free flow of water into the well. During the summer months, when biological growth was most severe, divers inspected and cleaned the orifice opening as required.

49. The tide station was inspected quarterly by a NOAA/NOS tide field group. Tide gage elevation was checked using existing NOS control positions, and the equipment was checked and adjusted as needed. Both NOS and FRF personnel also reviewed procedures for tending the gage and handling the data. Any specific comments on the previous months of data were discussed to ensure data accuracy.

50. Digital paper tape records of tide heights taken every 6 min were analyzed by the Tides Analysis Branch of NOS. An interpreter created a digital magnetic computer tape from the punch paper tape, which was then processed on a large computer. First, a listing of the instantaneous tidal height values was created for visual inspection. If errors were encountered, a computer program was used to fill in or recreate bad or missing data using correct values from the nearest NOS tide station and accounting for known time lags and elevation anomalies. The data were plotted, and a new listing was generated and rechecked. When the validity of the data had been confirmed, monthly tabulations of daily highs and lows, hourly heights (instantaneous

height selected on the hour), and various extreme and/or mean water level statistics were computed.

### Results

51. Tides at the FRF are semidiurnal with both daily high and low tides approximately equal. Tide height statistics are presented in Table 7. Figure 17 plots the monthly tide statistics for all available data, and Figure 18 compares the distribution of daily high- and low-water levels and hourly tide heights. The monthly or annual mean sea level (MSL) reported is the average of the hourly heights, whereas the mean tide level is midway between mean high water (MHW) and mean low water (MLW), which are the averages of the daily high- and low-water levels, respectively, relative to NGVD. Mean range (MR) is the difference between MHW and MLW levels, and the lowest water level for the month is the extreme low (EL) water, while the highest water level is the extreme high (EH) water level.

Table 7  
Tide Height Statistics\*

| <u>Month<br/>or<br/>Year</u> | <u>Mean<br/>High<br/>Water</u> | <u>Mean<br/>Tide<br/>Level</u> | <u>Mean<br/>Sea<br/>Level</u> | <u>Mean<br/>Low<br/>Water</u> | <u>Mean<br/>Range</u> | <u>Extreme<br/>High</u> | <u>Date</u> | <u>Extreme<br/>Low</u> | <u>Date</u> |
|------------------------------|--------------------------------|--------------------------------|-------------------------------|-------------------------------|-----------------------|-------------------------|-------------|------------------------|-------------|
| <u>1988</u>                  |                                |                                |                               |                               |                       |                         |             |                        |             |
| Jan                          | -                              | -                              | -                             | Gage Inoperative              |                       |                         | -           | -                      | -           |
| Feb                          | 47                             | 7                              | 7                             | -33                           | 80                    | 85                      | 28          | -69                    | 14          |
| Mar                          | 42                             | 2                              | 3                             | -37                           | 79                    | 80                      | 19          | -58                    | 20          |
| Apr                          | 58                             | 19                             | 19                            | -21                           | 79                    | 129                     | 13          | -62                    | 18          |
| May                          | 51                             | 10                             | 11                            | -30                           | 81                    | 88                      | 6           | -55                    | 14          |
| Jun                          | 50                             | 10                             | 10                            | -29                           | 79                    | 112                     | 3           | -51                    | 6           |
| Jul                          | 42                             | 1                              | 2                             | -39                           | 81                    | 74                      | 1           | -55                    | 30          |
| Aug                          | 46                             | 5                              | 6                             | -36                           | 82                    | 77                      | 31          | -60                    | 29          |
| Sep                          | 46                             | 6                              | 7                             | -34                           | 80                    | 89                      | 26          | -60                    | 23          |
| Oct                          | 46                             | 8                              | 8                             | -31                           | 77                    | 83                      | 25          | -63                    | 26          |
| Nov                          | 42                             | 3                              | 4                             | -36                           | 78                    | 93                      | 24          | -62                    | 20          |
| Dec                          | 37                             | -2                             | -2                            | -41                           | 78                    | 73                      | 13          | -72                    | 21          |
| 1988                         | 46                             | 6                              | 7                             | -33                           | 79                    | 129                     | Apr         | -72                    | Dec         |
| <u>Prior Years</u>           |                                |                                |                               |                               |                       |                         |             |                        |             |
| 1987                         | 55                             | 15                             | 16                            | -24                           | 79                    | 113                     | Jan         | -63                    | Nov         |
| 1986                         | 60                             | 13                             | 13                            | -35                           | 95                    | 123                     | Dec         | -108                   | Jan         |
| 1985                         | 59                             | 10                             | 11                            | -37                           | 96                    | 136                     | Dec         | -93                    | Apr         |
| 1984                         | 64                             | 16                             | 16                            | -32                           | 97                    | 147                     | Oct         | -77                    | Jul         |
| 1983                         | 68                             | 19                             | 19                            | -30                           | 98                    | 143                     | Jan         | -73                    | Mar         |
| 1982                         | 58                             | 8                              | 9                             | -42                           | 99                    | 127                     | Oct         | -108                   | Feb         |
| 1981                         | 59                             | 8                              | 9                             | -42                           | 101                   | 149                     | Nov         | -110                   | Apr         |
| 1980                         | 59                             | 8                              | 8                             | -43                           | 102                   | 118                     | Mar         | -119                   | Mar         |
| 1979                         | 60                             | 9                              | 9                             | -43                           | 103                   | 121                     | Feb         | -95                    | Sep         |
| 1979-<br>1988                | 59                             | 11                             | 12                            | -36                           | 95                    | 147                     | Nov 1981    | -119                   | Mar 1980    |

\* Measurements are in centimeters.

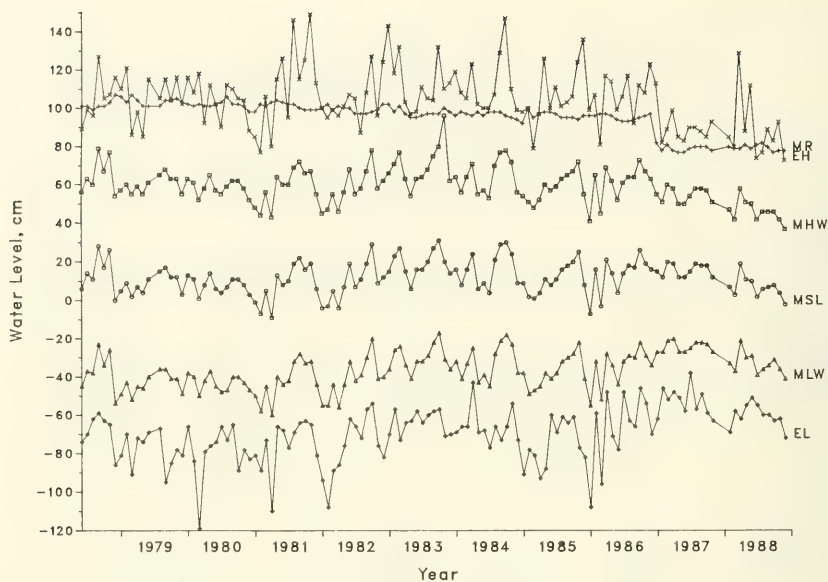


Figure 17. Monthly tide and water level statistics relative to NGVD



Figure 18. Distributions of hourly tide heights and high- and low-water levels

## PART VI: WATER CHARACTERISTICS

52. Monthly averages of daily measurements of surface water temperature, visibility, and density at the seaward end of the FRF pier are given in Table 8. The summaries represent single observations made near 0700 EST and, therefore, may not reflect daily average conditions since such characteristics can change within a 24-hr period. Large temperature variations were common when there were large differences between the air and water temperatures and variations in wind direction. From past experience, persistent onshore winds move warmer surface water toward the shoreline, although offshore winds cause colder bottom water to circulate shoreward resulting in lower temperatures.

Table 8  
Mean Surface Water Characteristics

| <u>Month</u> | <u>Temperature</u><br><u>deg C</u> |             | <u>Visibility</u><br><u>m</u> |             | <u>Density</u><br><u>g/cm<sup>3</sup></u> |             |
|--------------|------------------------------------|-------------|-------------------------------|-------------|---|-------------|
|              | <u>1980-</u>                       |             | <u>1980-</u>                  |             | <u>1980-</u>                              |             |
|              | <u>1988</u>                        | <u>1988</u> | <u>1988</u>                   | <u>1988</u> | <u>1988</u>                               | <u>1988</u> |
| Jan          | 4.6                                | 5.6         | 1.4                           | 1.2         | 1.0227                                    | 1.0234      |
| Feb          | 5.6                                | 4.7         | 2.2                           | 1.7         | 1.0237                                    | 1.0231      |
| Mar          | 7.3                                | 6.6         | 2.7                           | 1.5         | 1.0243                                    | 1.0229      |
| Apr          | 10.5                               | 10.8        | 1.5                           | 1.9         | 1.0242                                    | 1.0226      |
| May          | 15.5                               | 15.2        | 2.2                           | 2.3         | 1.0219                                    | 1.0222      |
| Jun          | 18.9                               | 19.3        | 2.5                           | 3.4         | 1.0220                                    | 1.0215      |
| Jul          | 21.3                               | 21.7        | 3.8                           | 3.8         | 1.0241                                    | 1.0218      |
| Aug          | 21.9                               | 23.2        | 4.7                           | 3.2         | 1.0239                                    | 1.0209      |
| Sep          | 21.6                               | 22.6        | 2.7                           | 2.3         | 1.0230                                    | 1.0211      |
| Oct          | 17.7                               | 18.9        | 1.5                           | 1.5         | 1.0237                                    | 1.0218      |
| Nov          | 14.7                               | 14.7        | 1.5                           | 1.0         | 1.0250                                    | 1.0230      |
| Dec          | 9.1                                | 10.1        | 1.8                           | 1.1         | 1.0259                                    | 1.0235      |
| Annual       | 14.1                               | 14.4        | 2.4                           | 2.1         | 1.0237                                    | 1.0223      |

### Temperature

53. Daily sea surface water temperatures (Figure 19) were measured with an NOS water sampler and thermometer. Monthly mean water temperatures (Table 8) varied with the air temperatures (see Table 2).

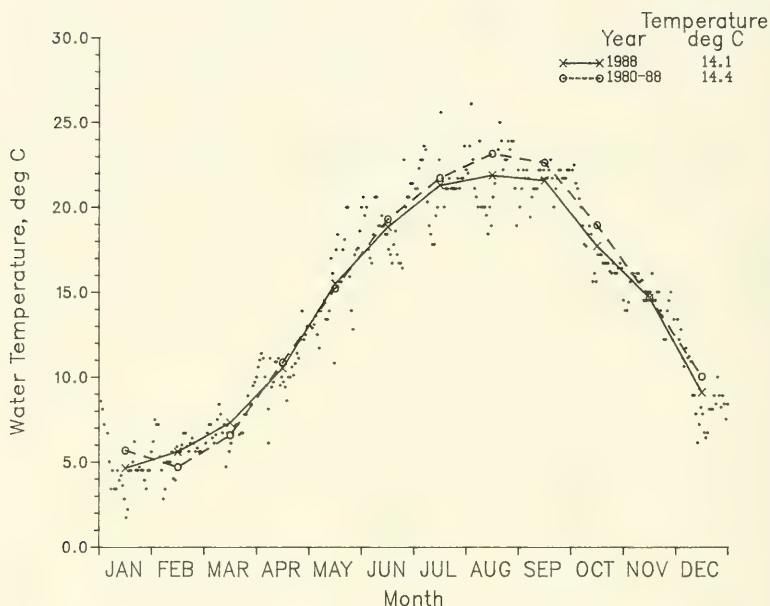


Figure 19. Daily water temperature values with monthly means

### Visibility

54. Visibility in coastal nearshore waters depends on the amount of salts, soluble organic material, detritus, living organisms, and inorganic particles in the water. These dissolved and suspended materials change the absorption and attenuation characteristics of the water which vary daily and yearly.

55. Visibility was measured with a 0.3-m-diam Secchi disk and, similar to water temperature, variation was related to onshore and offshore winds. Onshore winds moved warm clear surface water toward shore, whereas offshore winds brought up colder bottom water with large concentrations of suspended matter. Figure 20 presents the daily and monthly mean surface visibility values for the year. Large variations were common, and visibility less than 1 m was expected in any month. Monthly means are given in Table 8.



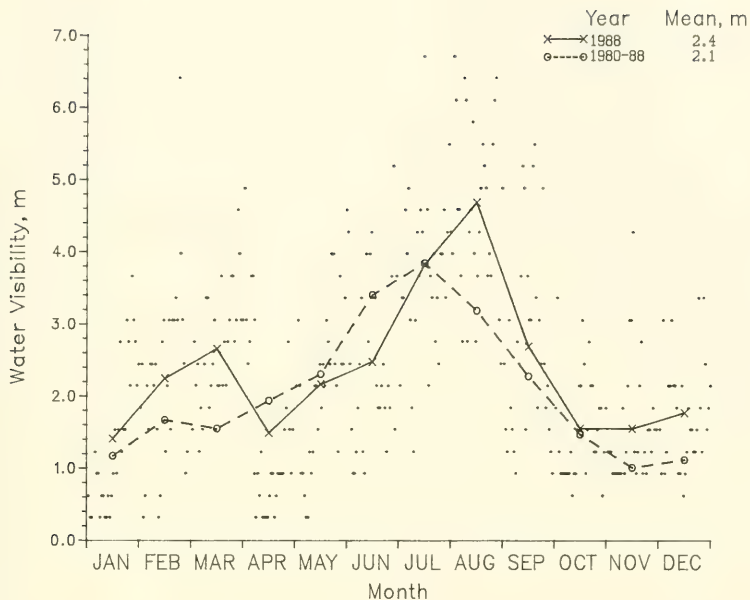


Figure 20. Daily water visibility values with monthly means

### Density

56. Daily and monthly mean surface density values, plotted in Figure 21, were measured with a hydrometer. Monthly means are also given in Table 8.

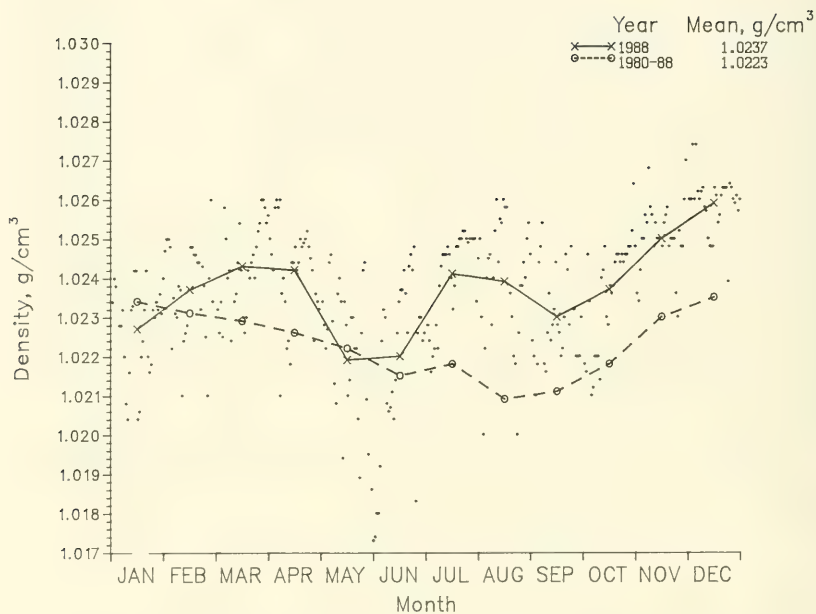


Figure 21. Daily water density values with monthly means

## PART VII: SURVEYS

57. Waves and currents interacting with bottom sediments produce changes in the beach and nearshore bathymetry. These changes can occur very rapidly in response to storms or slowly as a result of persistent but less forceful seasonal variations in wave and current conditions.

58. Nearshore bathymetry at the FRF is characterized by regular shore-parallel contours, a moderate slope, and a barred surf zone (usually an outer storm bar in water depths of about 4.5 m and an inner bar in water depths between 1.0 and 2.0 m). This pattern is interrupted in the immediate vicinity of the pier where a permanent trough runs under much of the pier, ending in a scour hole where depths can be up to 3.0 m greater than the adjacent bottom (Figure 22). This trough, which apparently is the result of the interaction of waves and currents with the pilings, varies in shape and depth with changing wave and current conditions. The effect of the pier on shore-parallel contours occurs as far as 300 m away, and the shoreline may be affected up to 350 m from the pier (Miller, Birkemeier, and DeWall 1983).

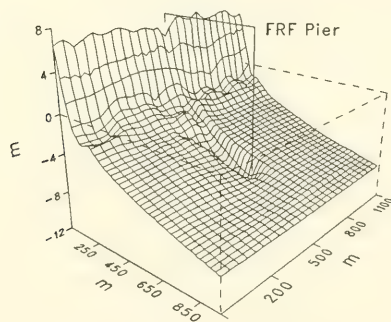


Figure 22. Permanent trough under the FRF pier, 8 July 1988

59. To document the temporal and spatial variability in bathymetry, surveys were conducted approximately monthly of an area extending 600 m north and south of the pier and approximately 950 m offshore. Contour maps resulting from these surveys along with plots of change in elevation between surveys are given in Appendix A.

60. All surveys utilized the Coastal Research Amphibious Buggy (CRAB), a 10.7-m-tall amphibious tripod, and a Zeiss electronic surveying system described by Birkemeier and Mason (1984). The profile locations are shown in each figure in Appendix A. Survey accuracy was about  $\pm 3$  cm horizontally and vertically. Monthly soundings along both sides of the FRF pier were collected by lowering a weighted measuring tape to the bottom and recording the distance below the pier deck. Soundings were taken midway between the pier pilings to minimize errors caused by scour near the pilings.

61. A history of bottom elevations below Gages 645 and 625 is presented in Figure 23 for their respective pier stations of sta 7+80 (238 m) and sta 19+00 (579 m) along with intermediate locations, 323 and 433 m.

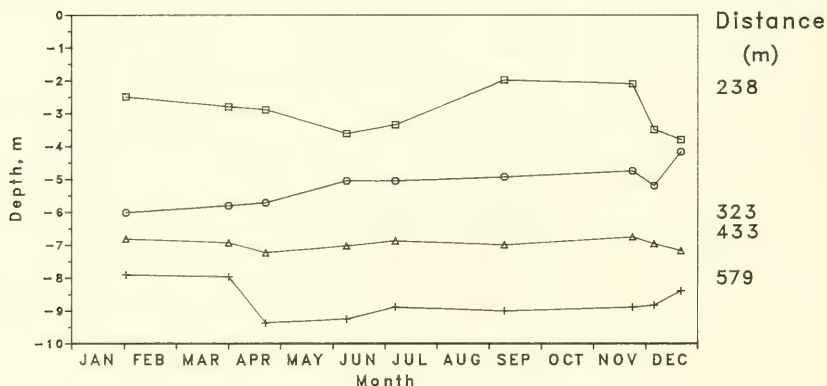


Figure 23. Time-history of bottom elevations at selected locations under the FRF pier

## PART VIII: PHOTOGRAPHY

### Aerial Photographs

62. Aerial photography was taken quarterly using a 23-cm aerial mapping camera at a scale of 1:12,000. All coverage was at least 60-percent overlap, with flights flown as closely as possible to low tide between 1000 and 1400 EST with less than 10-percent cloud cover. The flight lines covered are shown in Figure 24. Figure 25 is a sample of the imagery obtained on 12 August 1988; the available aerial photographs for the year are:

| <u>Date</u> | <u>Flight Lines</u> | <u>Format</u> |
|-------------|---------------------|---------------|
| 6 Jan       | 2                   | Color         |
|             | 3                   | B/W           |
| 25 Apr      | 2                   | Color         |
|             | 3                   | B/W           |
| 12 Aug      | Part of 1           | B/W           |
|             | 3                   | B/W           |
| 27 Sep      | 2                   | Color         |
| 9 Oct       | 3                   | B/W           |
|             | 2                   | Color         |
|             | Rest of 1           | B/W           |

### Beach Photographs

63. Daily color slides of the beach were taken using a 35-mm camera from the same location on the pier looking north and south (Figure 26). The location from which each picture was taken, as well as the date, time, and a brief description of the picture, was marked on the slides.

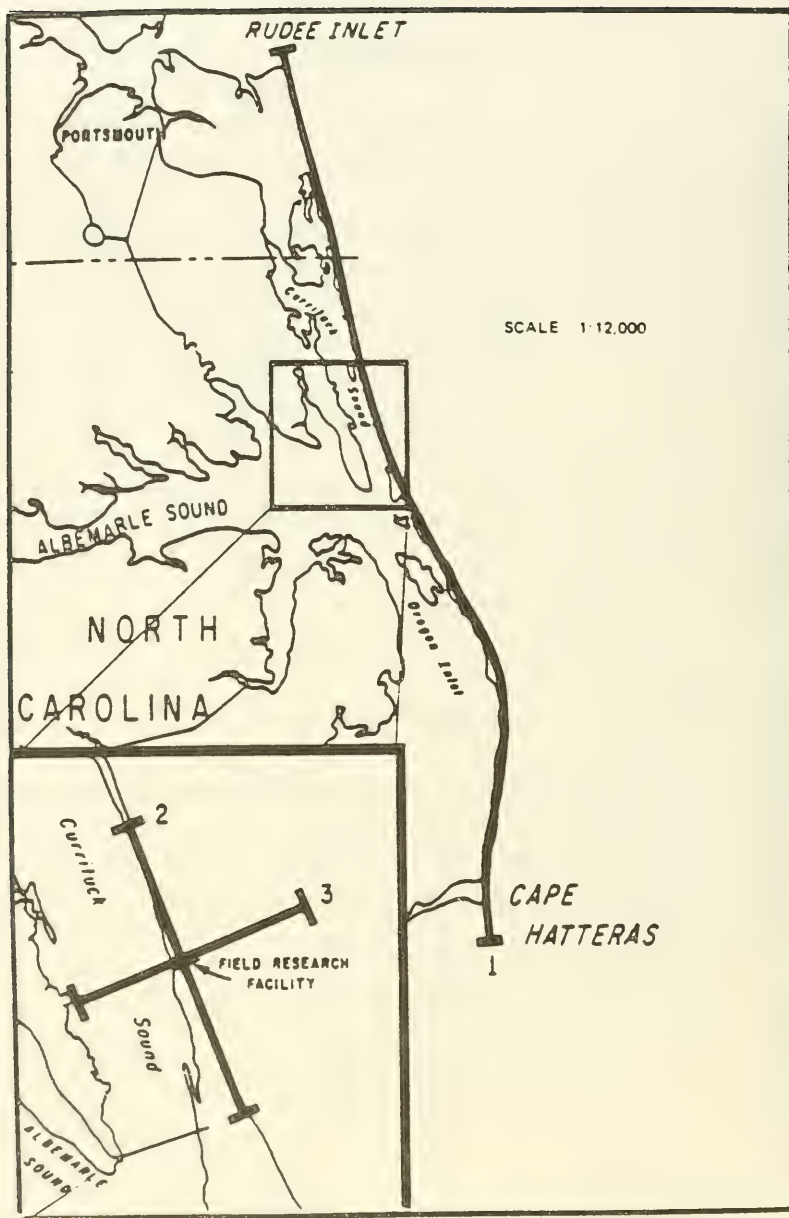


Figure 24. Aerial photography flight lines



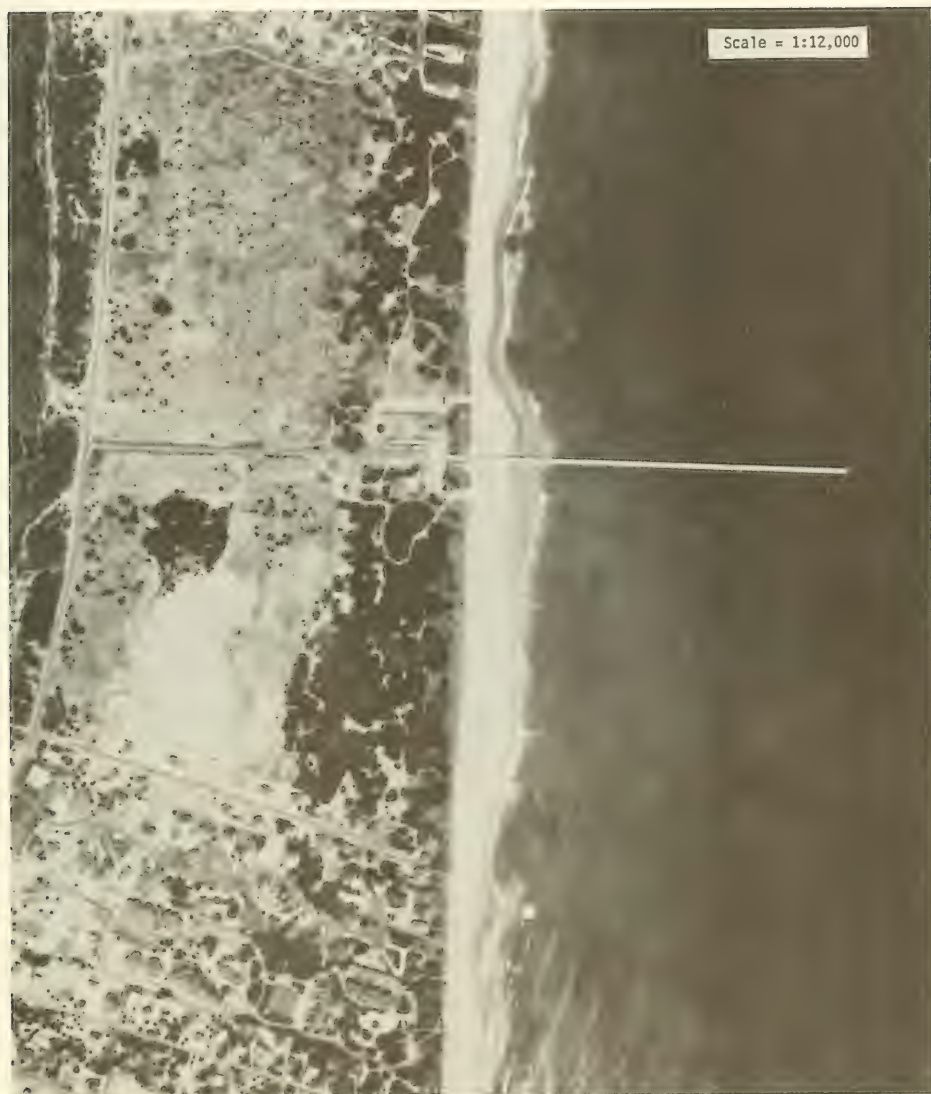
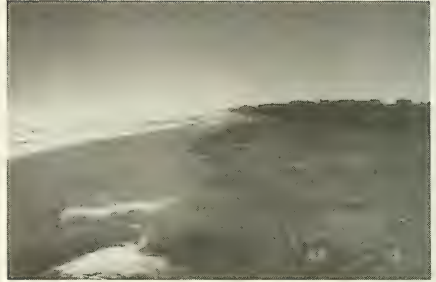


Figure 25. Sample aerial photograph, 12 August 1988

North View

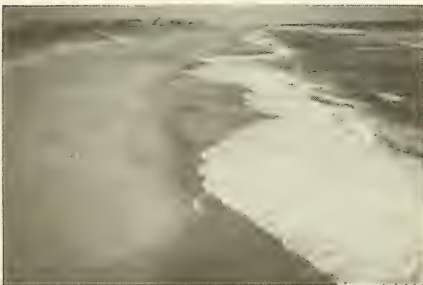
South View



a. 16 January 1988



b. 13 February 1988

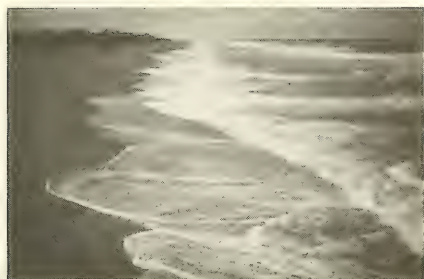


c. 11 March 1988

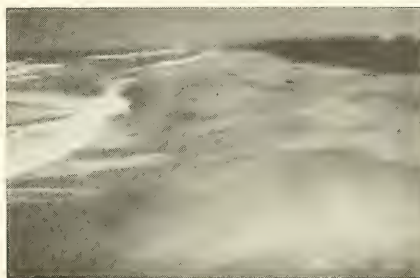
Figure 26. Beach photos looking north and south from the FRF pier  
(Sheet 1 of 4)

North View

South View



a. 12 April 1988



b. 16 May 1988

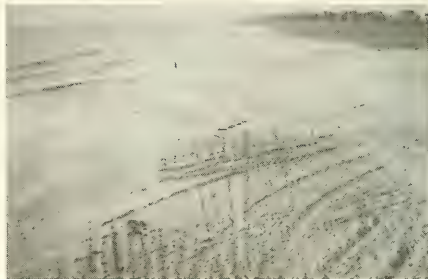


c. 12 June 1988

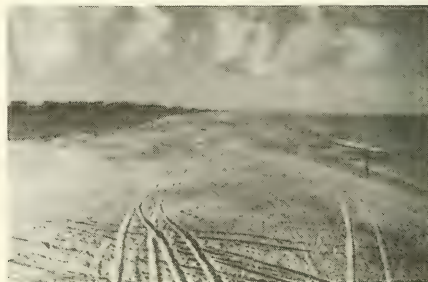
Figure 26. (Sheet 2 of 4)

North View

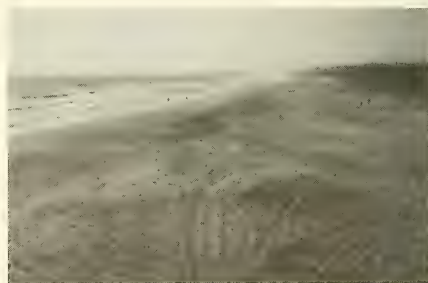
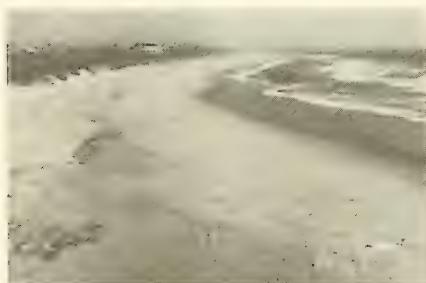
South View



a. 15 July 1988



b. 12 August 1988

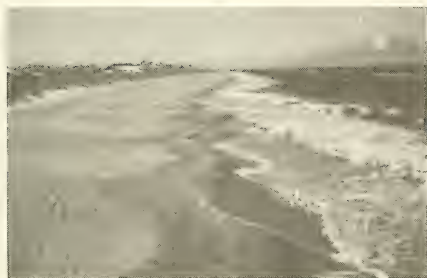


c. 3 September 1988

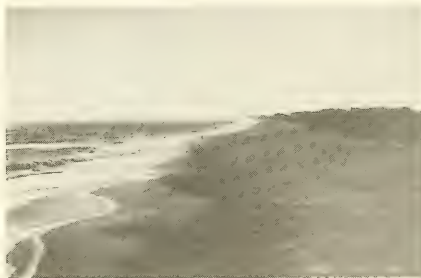
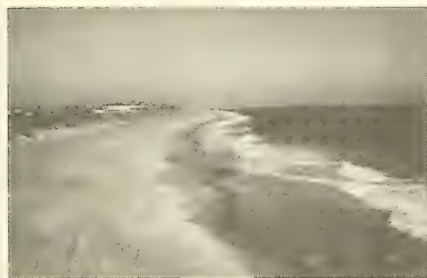
Figure 26. (Sheet 3 of 4)

North View

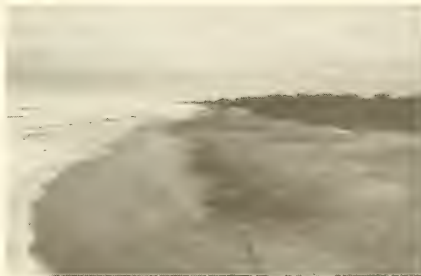
South View



a. 13 October 1988



b. 14 November 1988



c. 15 December 1988

Figure 26. (Sheet 4 of 4)



## PART IX: STORMS

64. This section discusses storms (defined here as times when the wave height parameter,  $H_{m0}$ , equaled or exceeded 2 m at the seaward end of the FRF pier). Sample spectra from Gage 630 are given in Appendix B. Prestorm and/or poststorm bathymetry diagrams are given in Appendix A. Tracking information was provided by NOAA Daily Weather Maps (US Department of Commerce 1988).  
3 January 1988 (Figure 27)

65. Early on 2 January, strong onshore winds (from north-northeast) generated by a high pressure system centered over Illinois began to affect the FRF. Late on 3 January, the maximum wind speeds exceeded 14 m/sec and the maximum  $H_{m0}$  (Gage 625) of 2.19 m ( $T_p = 7.53$  sec) was recorded. Precipitation totaled 27 mm.

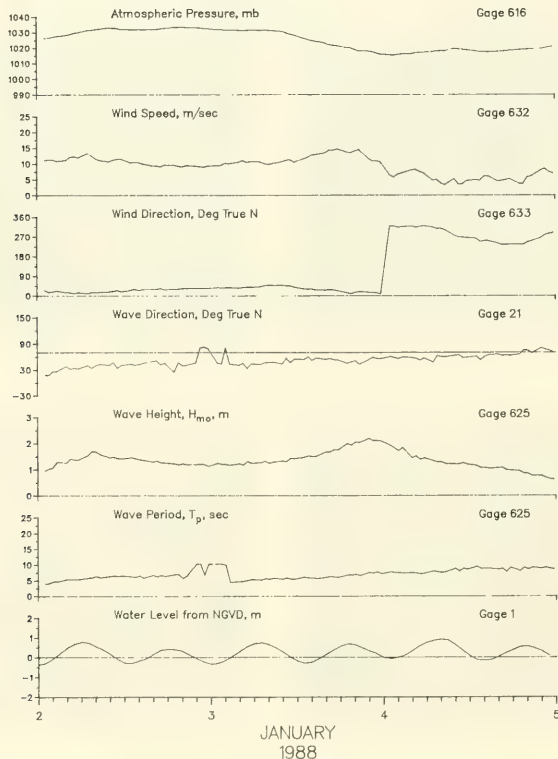


Figure 27. Data for 3 January 1988 storm

### 7-8 January 1988 (Figure 28)

66. Onshore winds, generated by a Canadian high pressure system, were reinforced by the formation of a storm off the NC coast late on 7 January. The storm moved rapidly up the coast and reached Maine by 9 January. Peak winds (from northeast) exceeded 16 m/sec at 0242 EST on 8 January. Several hours later, the maximum  $H_{m0}$  (Gage 625) of 2.85 (  $T_p = 7.76$  sec) and minimum atmospheric pressure of 1011.3 mb were recorded. Precipitation totaled 25 mm.

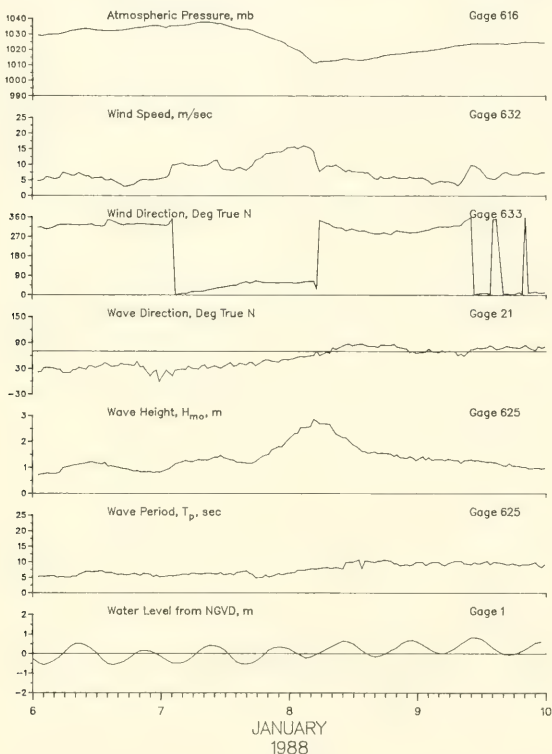


Figure 28. Data for 7-8 January 1988 storm



14 January 1988 (Figure 29)

67. A strong high pressure system centered over Illinois produced strong onshore winds (from northeast) at the FRF beginning late on 13 January and continuing through the 14th. The maximum wind speed (exceeding 17 m/sec) and the maximum  $H_{mo}$  (Gage 625) of 2.50 ( $T_p = 7.11$  sec) were both recorded at 0700 EST on the 14th.

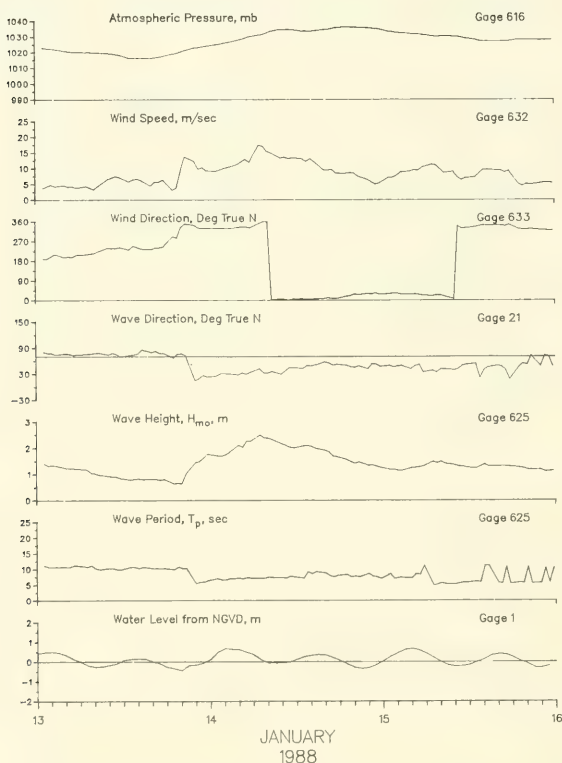


Figure 29. Data for 14 January 1988 storm

## 12 February 1988 (Figure 30)

68. This storm formed over Texas early on 10 February and rapidly intensified as it moved to the north-northeast. By 12 February, it was located over Lake Erie, and two weak secondary lows formed in the Atlantic (one off Cape Hatteras, NC). All three lows merged over New England by 13 February. Maximum onshore winds (from east-northeast) approached 7 m/sec at 0134 EST on 12 February followed several hours later by the maximum  $H_{mo}$  (Gage 625) of 2.25 m ( $T_p = 9.14$  sec). Minimum atmospheric pressure was 1006.8 mb, and precipitation totaled 25 mm.

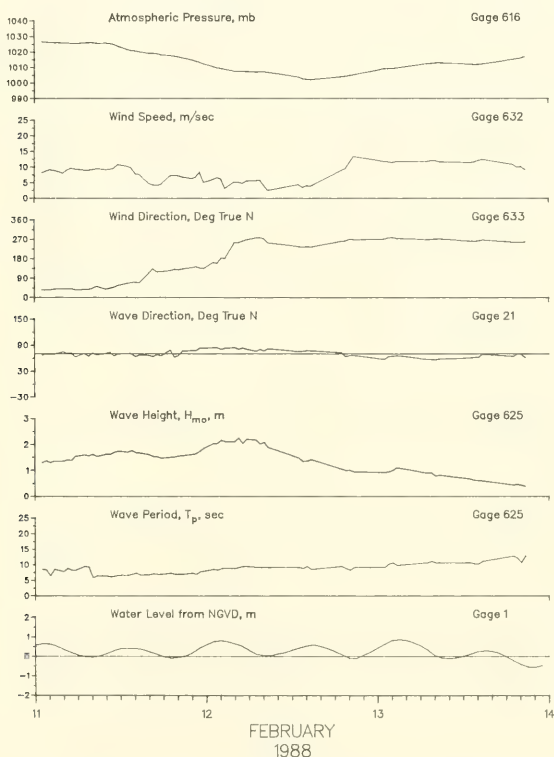


Figure 30. Data for 12 February 1988 storm

28 February 1988 (Figure 31)

69. Generically known as "Alberta Clipper," this storm roared out of Canada on 26 February and was located off Cape Hatteras, NC, by 28 February. Northerly winds exceeded 16 m/sec early on the 28th with the maximum  $H_{m0}$  (Gage 625) of 2.76 m ( $T_p = 8.00$  sec) recorded the same morning. The minimum atmospheric pressure of 1004.4 mb occurred at 1442 EST on 27 February. There was no measurable precipitation with this storm.

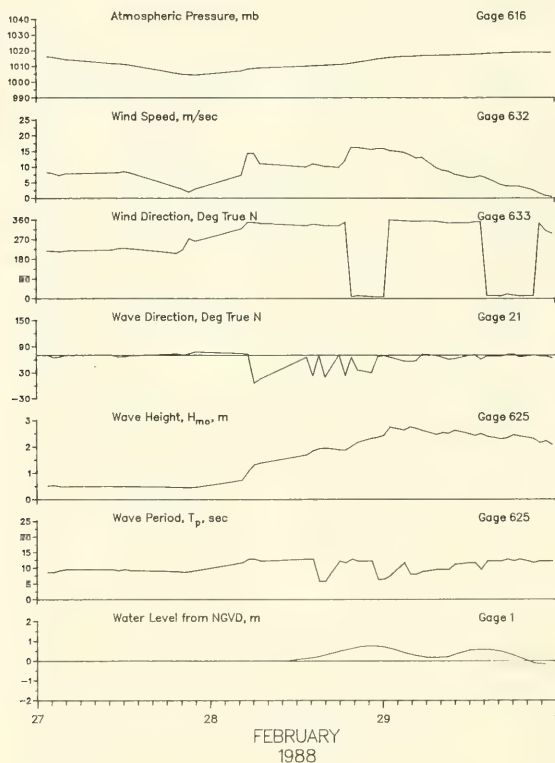


Figure 31. Data for 28 February 1988 storm

11 March 1988 (Figure 32)

70. This weak storm formed over Texas early on 9 March and tracked east. Centered over North Carolina on 10 March, the storm quickly moved offshore. Maximum wind speeds (from north-northeast) exceeded 15 m/sec at 2342 EST on 10 March. Wave heights exceeded 2 m only 3 hr with the maximum  $H_{mo}$  (Gage 625) of 2.2 m ( $T_p = 6.9$  sec) occurring at 0208 EST on 11 March. The lowest atmospheric pressure of 999.2 mb was recorded at 0842 EST on 10 March. Precipitation totaled 4 mm.

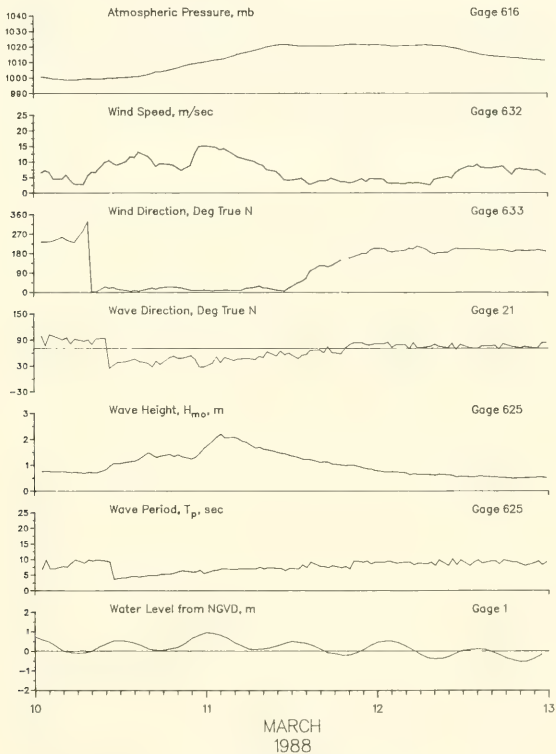


Figure 32. Data for 11 March 1988 storm

8 April 1988 (Figure 33)

71. This storm formed over the southwestern United States on 30 March and slowly strengthened as it approached the Great Lakes. It dropped to the southeast passing over the Virginia coast early on 8 April and rapidly moved into the Atlantic. On 8 April at 0734 EST, the maximum wind speeds (from north) neared 16 m/sec and the maximum  $H_{mo}$  (Gage 625) was 2.8 m ( $T_p = 9.85$  sec). The minimum atmospheric pressure of 994.7 mb occurred early on 7 April. Precipitation amounted to 30 mm.

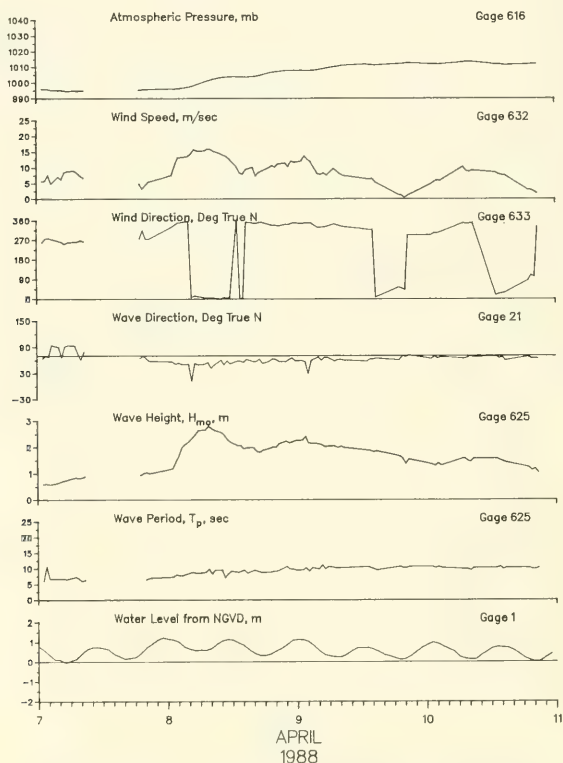


Figure 33. Data for 8 April 1988 storm

12-14 April 1988 (Figure 34)

72. After forming over the Gulf of Mexico on 10 April, this storm continued to strengthen as it tracked across the southeast. By 12 April, it was still well inland over Alabama; however, strong onshore winds were being generated at the FRF. As it continued to intensify, the forward movement of the storm slowed, finally moving offshore at Cape Hatteras, NC, on 13 April. This northeaster caused coastal erosion (resulting in the demise of several beach cottages) and flooding at a number of locations along the Outer Banks. Peak winds (from northeast) exceeded 21 m/sec early on 13 April with winds above 15 m/sec continuing for 37 hr. The minimum atmospheric pressure (1001.0 mb) occurred at 0700 EST on 13 April, and the maximum  $H_{m0}$  of 4.96 m ( $T_p = 10.24$  sec) at Gage 630 occurred several hours later. Total precipitation was 47 mm.

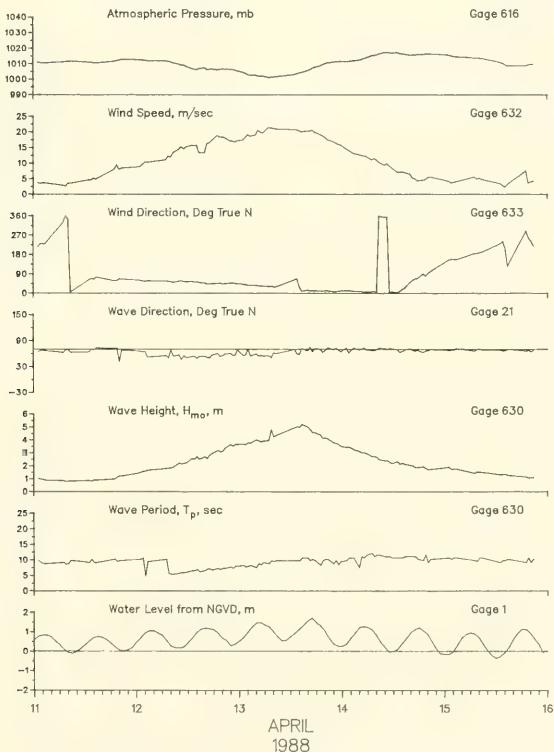


Figure 34. Data for 12-14 April 1988 storm

19 April 1988 (Figure 35)

73. This weak low pressure system began as a cold front over Louisiana on 18 April, rapidly moved to the northeast, and by 20 April moved well offshore. Maximum winds (from north) exceeded 19 m/sec on the afternoon of the 19th while the maximum  $H_{mo}$  (Gage 625) of 2.17 m ( $T_p = 6.92$  sec) was attained several hours later. The minimum atmospheric pressure was 1000.8 mb, and precipitation totaled 19 mm.

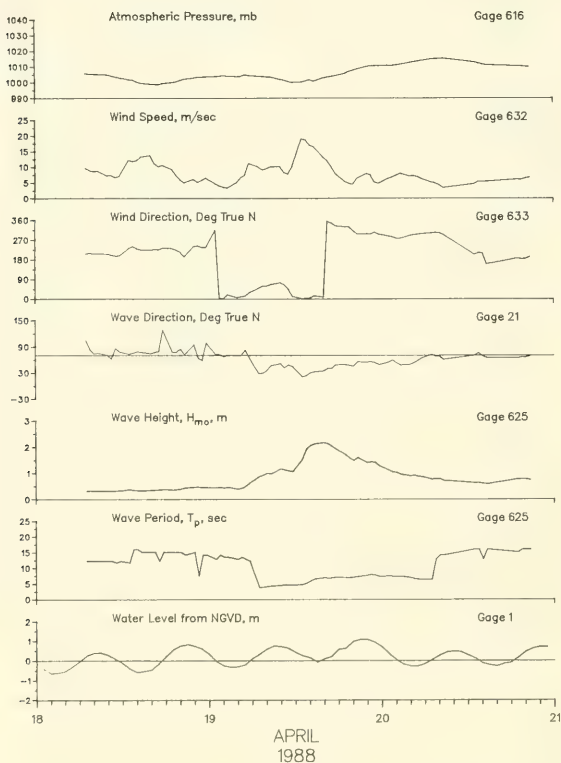


Figure 35. Data for 19 April 1988 storm



3-5 June 1988 (Figure 36)

74. This small coastal storm developed off Cape Hatteras, NC, early on 3 June and rapidly moved offshore. Maximum onshore winds (from north-northeast) exceeded 15 m/sec at 1934 EST on 3 June. This was closely followed by the maximum  $H_{m0}$  (Gage 625) of 2.40 m ( $T_p = 7.53$  sec). Also on 3 June, the minimum atmospheric pressure of 1005.3 mb was recorded at 0842 EST. Total precipitation was 27 mm.

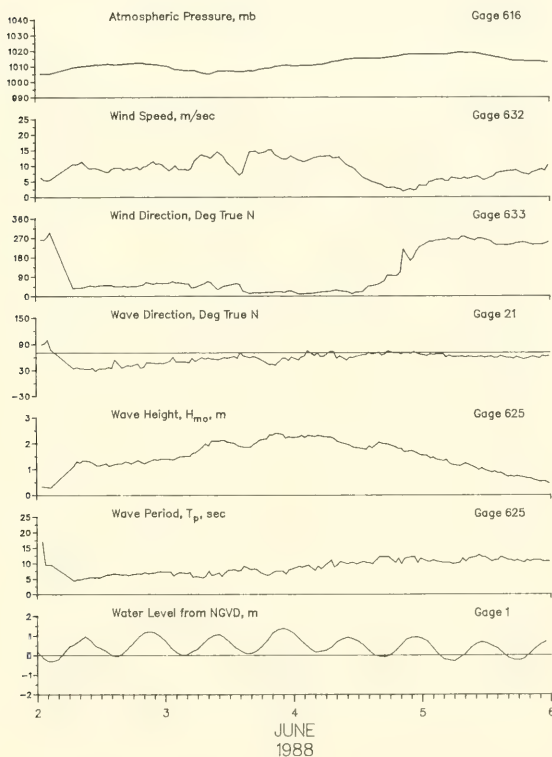


Figure 36. Data for 3-5 June 1988 storm

#### 4 October 1988 (Figure 37)

75. On 3 October, this storm developed in the Gulf of Mexico off the Florida coast, quickly intensified as it moved up the eastern coast, and was located off Cape Hatteras, NC, early on 4 October. By the morning of 5 October, it was located off the New England coast. Maximum winds (from north-northeast) exceeding 16 m/sec peaked at 1000 EST on 4 October, and the maximum  $H_{mo}$  (Gage 625) of 2.29 m ( $T_p = 6.56$  sec) was recorded at 0842 EST on the same day. The minimum atmospheric pressure of 1008 mb was recorded at 0700 EST on 4 October. Total precipitation was 25 mm.

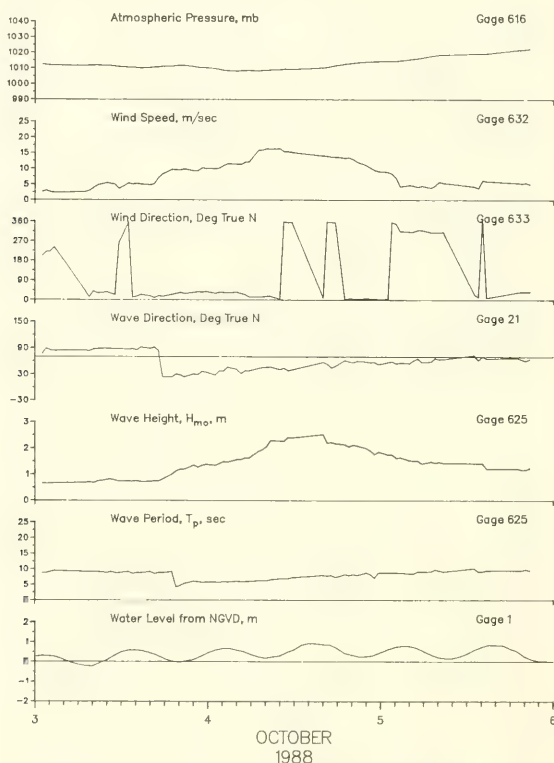


Figure 37. Data for 4 October 1988 storm

8 October 1988 (Figure 38)

76. Following the small storm on 4 October, winds continued onshore. With the addition of a strong Canadian high pressure system on 7 October, waves briefly exceeded 2 m. Maximum wind speeds (from north) recorded on 7 October exceeded 13 m/sec at 1334 EST; maximum  $H_{mo}$  of 2.07 m ( $T_p$  = 6.92 sec) at Gage 625 occurred at 0208 EST on 8 October.

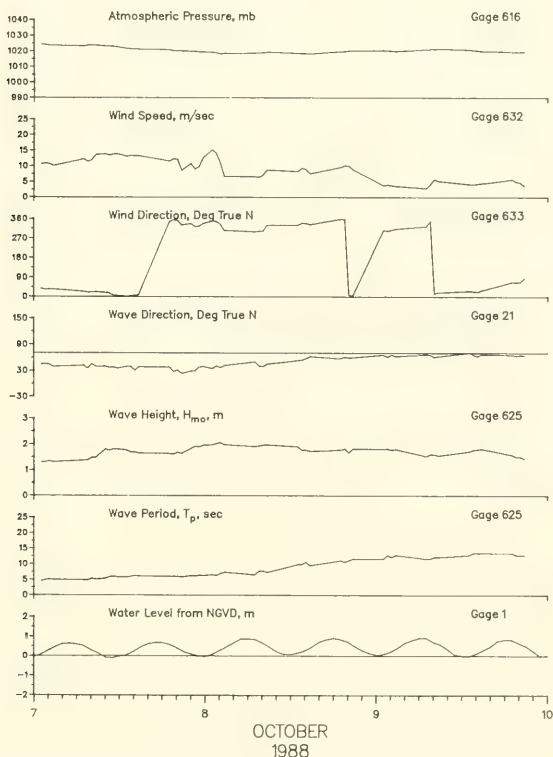


Figure 38. Data for 8 October 1988 storm

1 November 1988 (Figure 39)

77. Forming off the Georgia coast early on 1 November, this storm moved rapidly past the FRF and was located off New England by the next day. Maximum onshore winds (from northeast) peaked near 11 m/sec at 0208 EST on 1 November. At 1442 EST the maximum  $H_{m0}$  (Gage 625) of 2.41 m ( $T_p = 6.92$  sec) was recorded, and at 1600 EST the minimum atmospheric pressure of 1003.3 mb was recorded. Total precipitation was 30 mm.

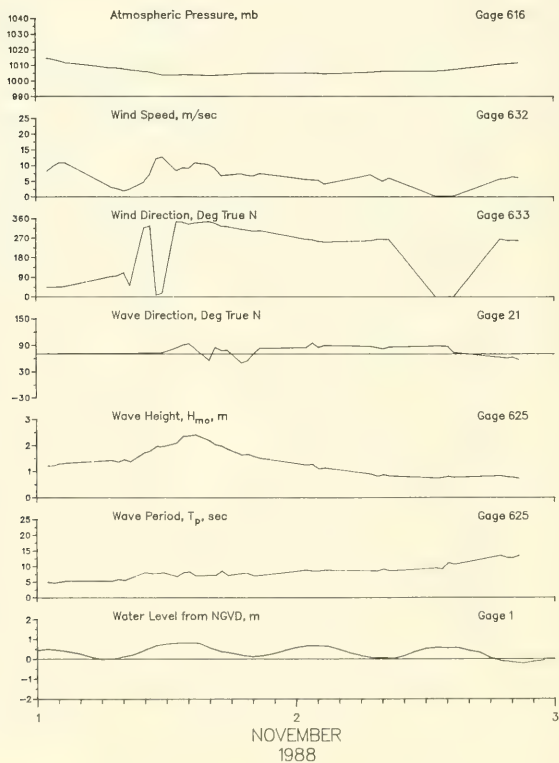


Figure 39. Data for 1 November 1988 storm

24 November 1988 (Figure 40)

78. Forming in the Gulf of Mexico, Tropical Storm Keith slowly followed a cold front across Florida on 22-23 November and continued to move to the northeast into the Atlantic on 24 November. The combination of a strong Canadian high pressure system and this offshore tropical storm produced storm waves on the 24th. Maximum onshore winds (from north-northeast) reached 14 m/sec at 0208 EST on the 24th followed shortly (0400 EST) by the minimum atmospheric pressure of 1010.1 mb. The maximum  $H_{mo}$  (Gage 111) of 2.47 m ( $T_p = 7.30$  sec) was recorded at 1600 EST. There was no precipitation.

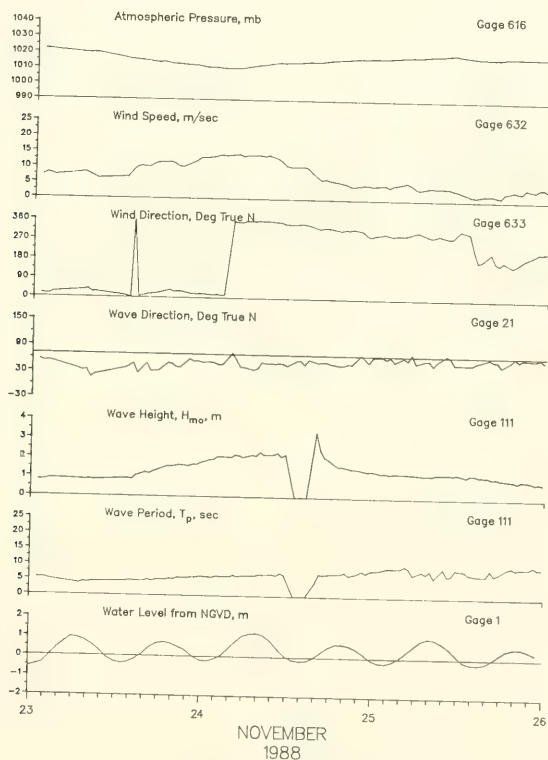


Figure 40. Data for 24 November 1988 storm

4 December 1988 (Figure 41)

79. A strong high pressure system centered over the southeastern United States in combination with a storm located in Canada produced strong winds on 4 December. Maximum winds (from north-northwest) exceeding 15 m/sec were recorded at 1034 EST on 4 December, and at 1142 EST the maximum  $H_{m0}$  (Gage 111) of 2.29 m ( $T_p = 7.31$  sec) was recorded.

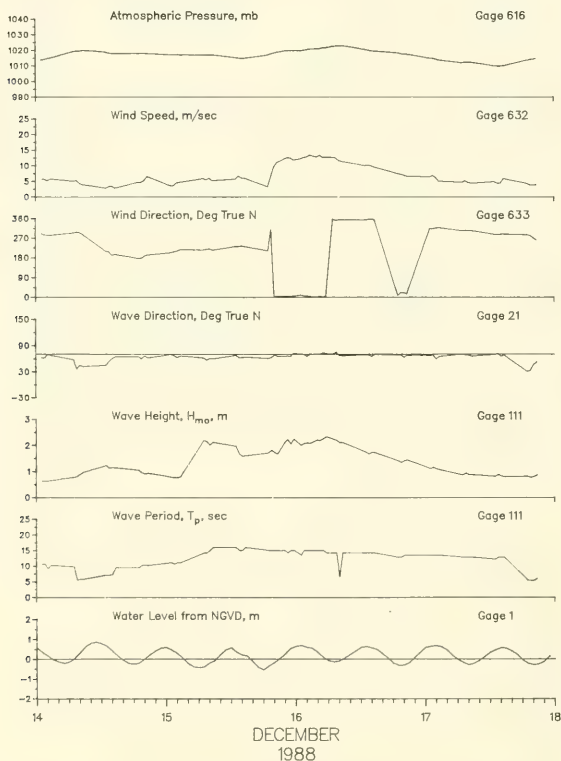


Figure 41. Data for 4 December 1988 storm

15-16 December 1988 (Figure 42)

80. A strong storm located well offshore followed a track parallel to the east coast and generated northerly winds that peaked in excess of 13 m/sec at 0242 EST on 16 December. At 0542 EST that same day, maximum  $H_{m0}$  (Gage 111) of 2.34 m ( $T_p = 14.22$  sec) was recorded. Because the storm remained well offshore, the atmospheric pressure was only slightly affected. There was no precipitation.

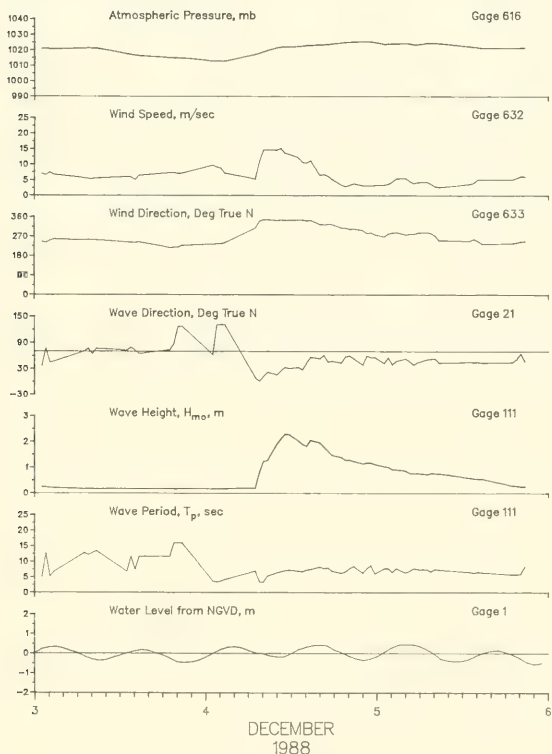


Figure 42. Data for 15-16 December 1988 storm



## REFERENCES

- Bingham, C., Godfrey, M. D., and Tukey, J. W. 1967. "Modern Techniques of Power Spectrum Estimation," IEEE Trans. Audio Electroacoustics, AU-15, pp 56-66.
- Birkemeier, W. A., and Mason, C. 1984. "The CRAB: A Unique Nearshore Surveying Vehicle," Journal of Surveying Engineering, American Society of Civil Engineers, Vol 110, No. 1.
- Field Research Facility. 1988 (Jan-Dec). "Preliminary Data Summary," Monthly Series, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Grogg, W. E., Jr. 1986. "Calibration and Stability Characteristics of the Baylor Staff Wave Gage," Miscellaneous Paper CERC-86-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Miller, H. C. 1980. "Instrumentation at CERC's Field Research Facility, Duck, North Carolina," CERC Miscellaneous Report 80-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Miller, H. C., Birkemeier, W. A., and DeWall, A. E. 1983. "Effect of the CERC Research Pier on Nearshore Processes," Coastal Structures '83, American Society of Civil Engineers, Arlington, VA, pp 769-785.
- US Department of Commerce. 1988. "Daily Weather Maps," Weekly Series, Washington, DC.
- Welch, P. D. 1967. "The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short Modified Periodograms," IEEE Trans. Audio Electroacoustics, AE-15, pp 70-73.

## APPENDIX A: SURVEY DATA

1. Contour diagrams constructed from the bathymetric survey data are presented in this appendix. The profile lines surveyed are identified on each diagram. Contours are in half meters referenced to National Geodetic Vertical Datum (NGVD). The distance offshore is referenced to the Field Research Facility (FRF) monumentation baseline behind the dune.

2. Change in FRF bathymetry diagrams constructed by contouring the difference between two contour diagrams are also presented with contour intervals of 0.25 m. Wide contour lines show areas of erosion. Other areas correspond to areas of accretion. Although these change diagrams are based on considerable interpolation of the original survey data, they do facilitate comparison of the contour diagrams.

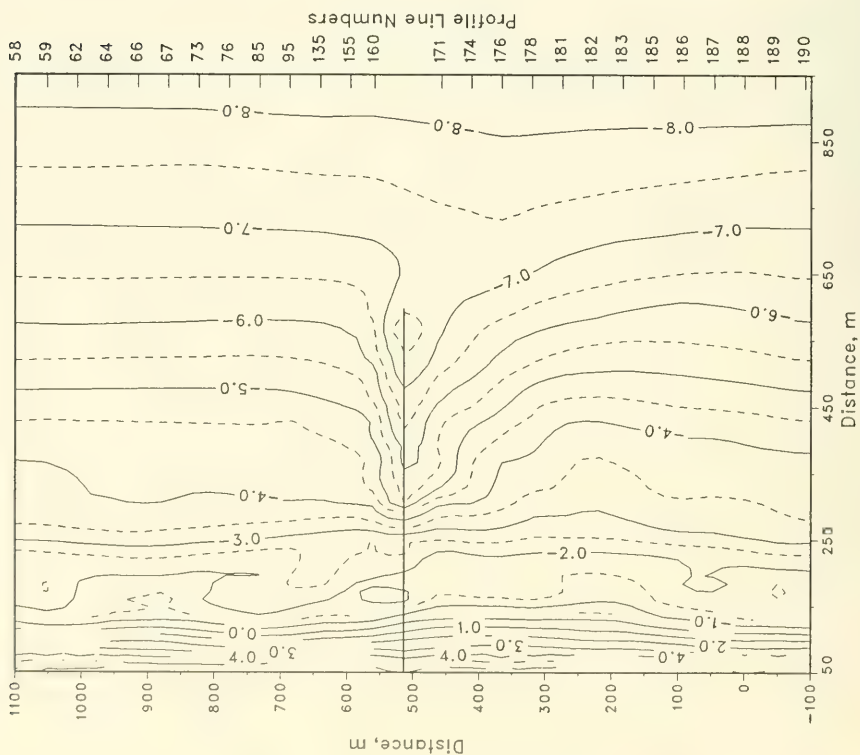
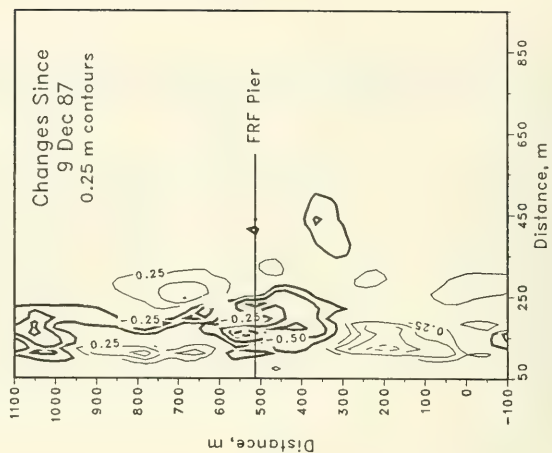
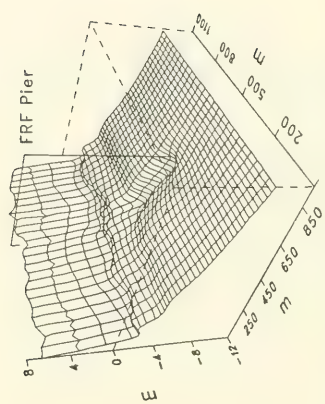


Figure A1. FRF Bathymetry 2 February 88 (depths relative to NGVD)

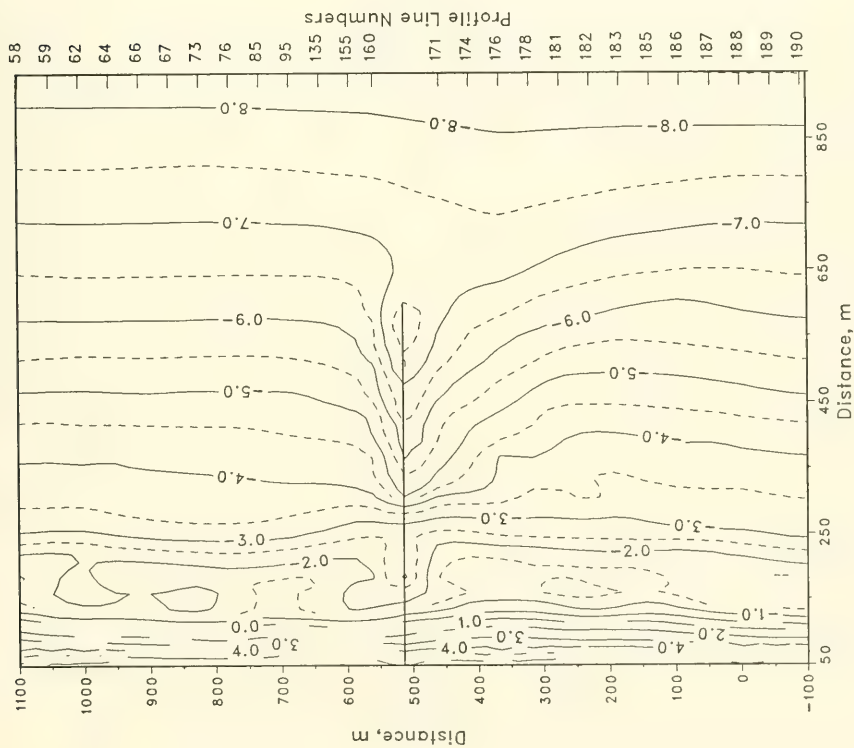
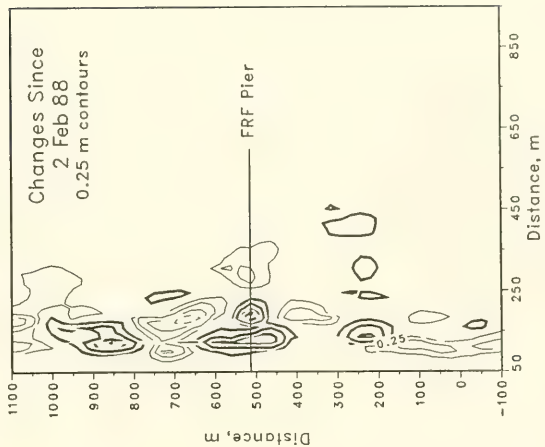
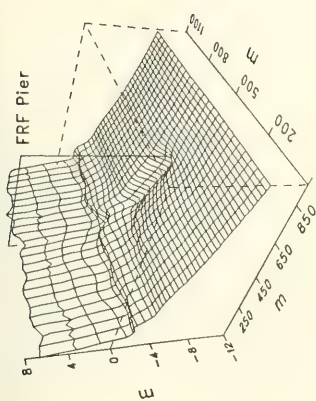


Figure A2. FRF Bathymetry 30 March 88 (depths relative to NGVD)

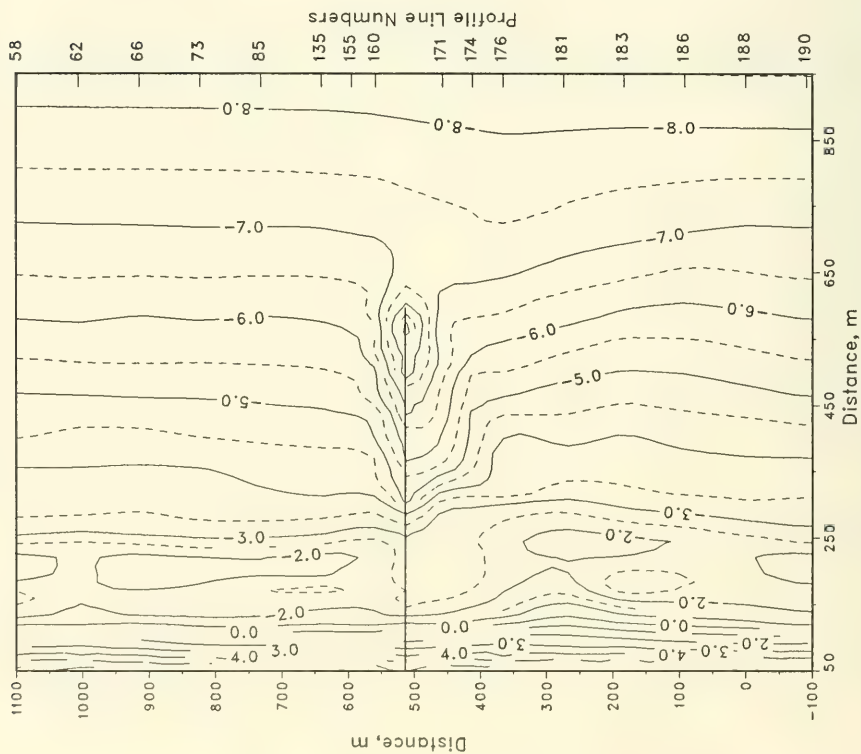
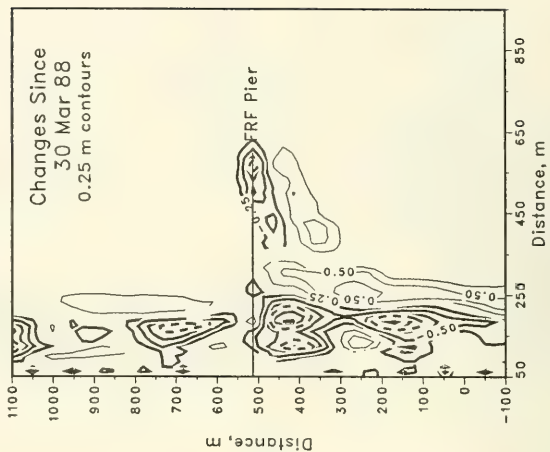
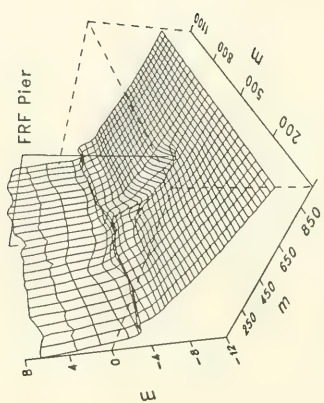


Figure A3. FRF Bathymetry 21 April 88 (depths relative to NGVD)

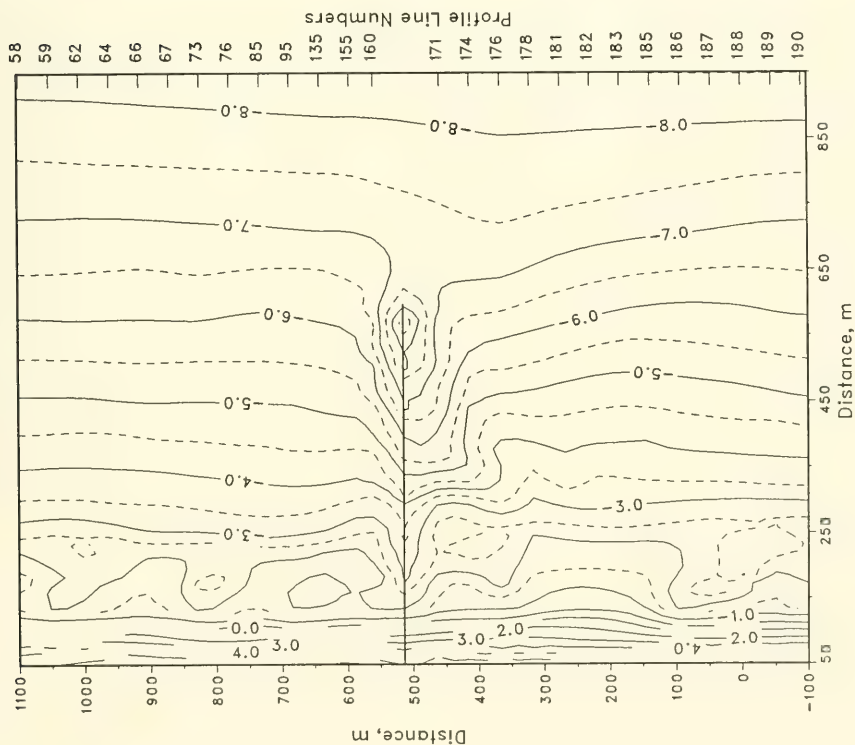
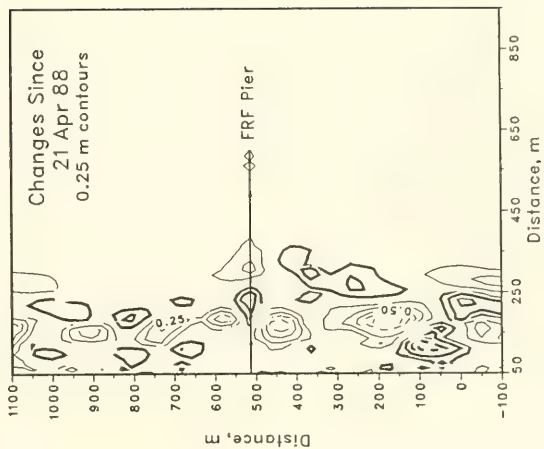
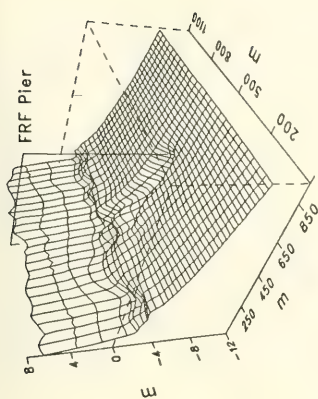


Figure A4. FRF Bathymetry 8 June 88 (depths relative to NGVD)

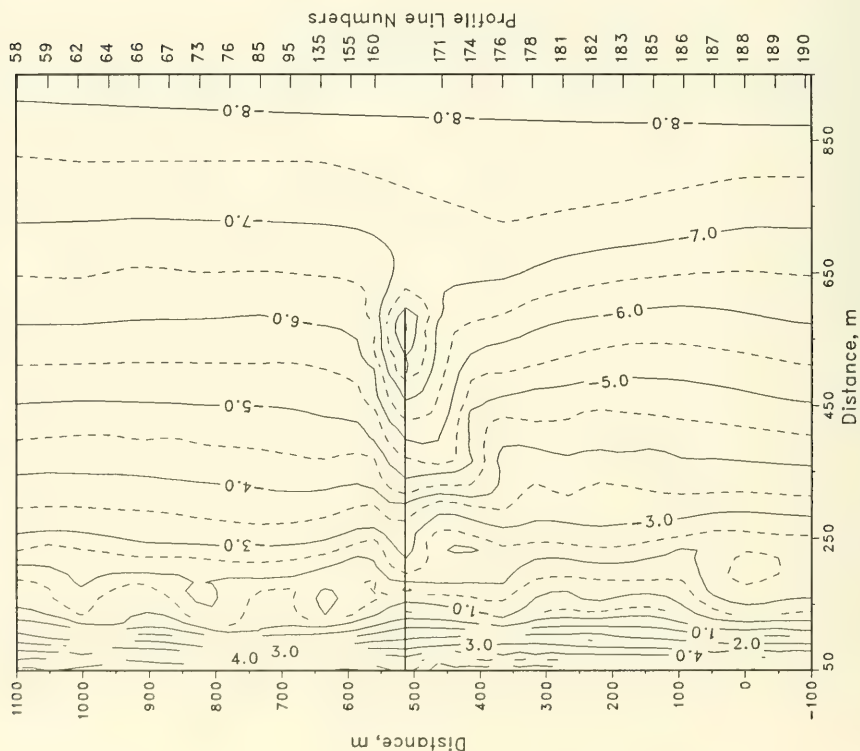
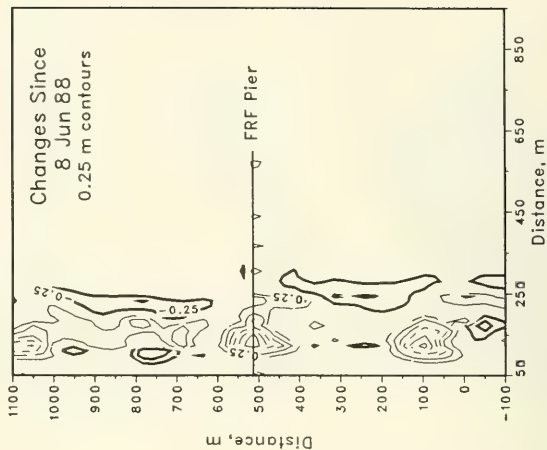
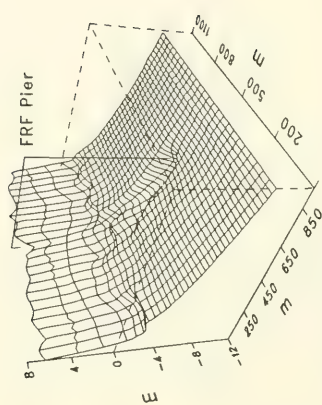


Figure A5. FRF Bathymetry 8 July 88 (depths relative to NGVD)



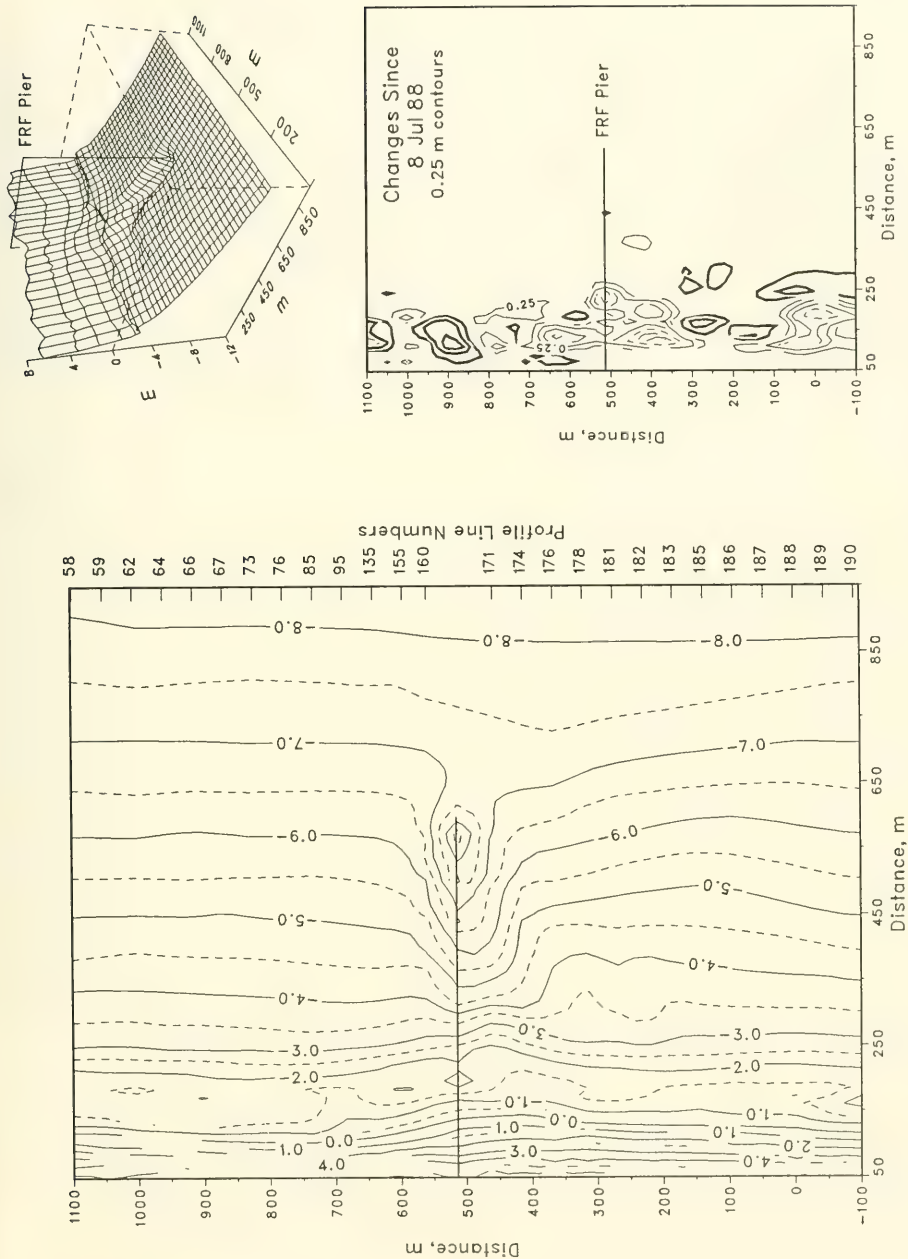


Figure A6. FRF Bathymetry 9 September 88 (depths relative to NGVD)

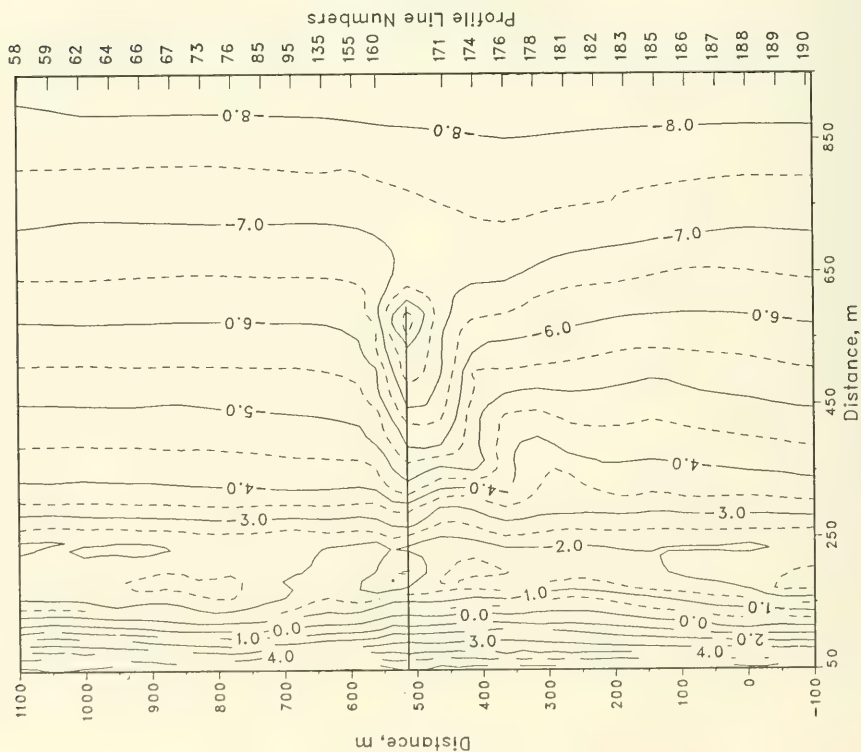
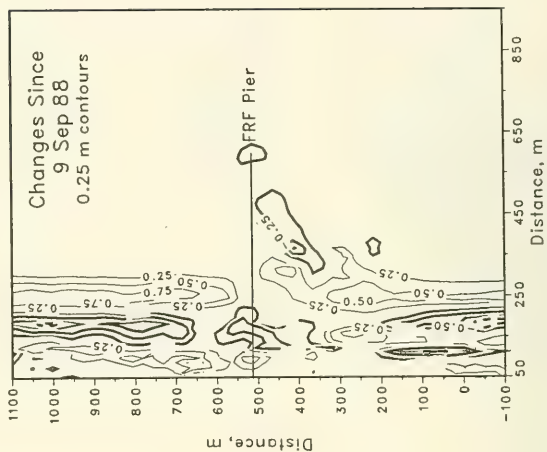
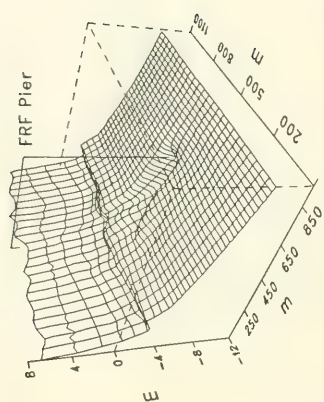


Figure A7. FRF Bathymetry 21 November 88 (depths relative to NGVD)

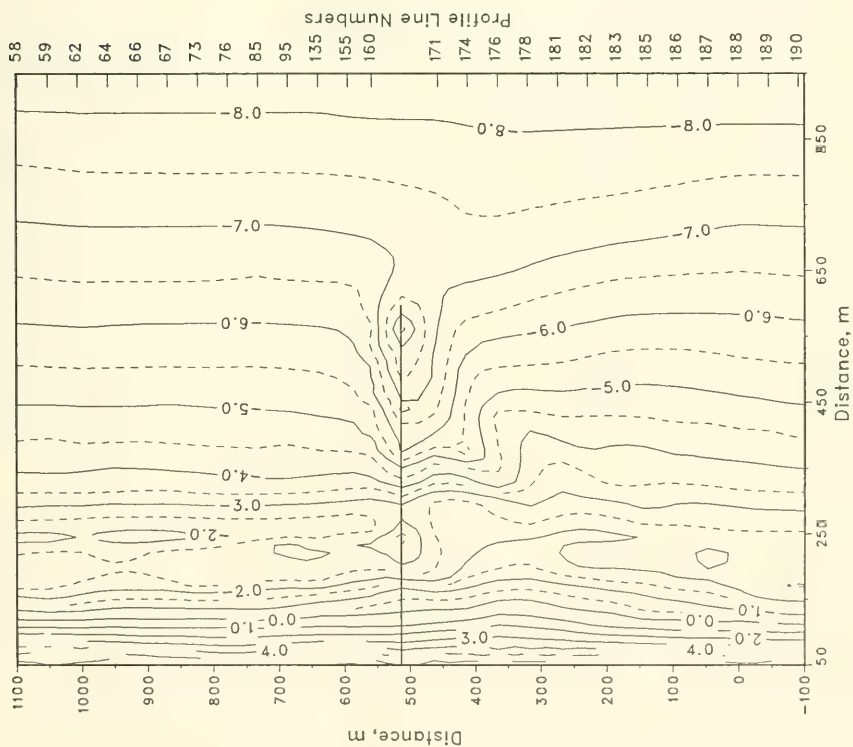
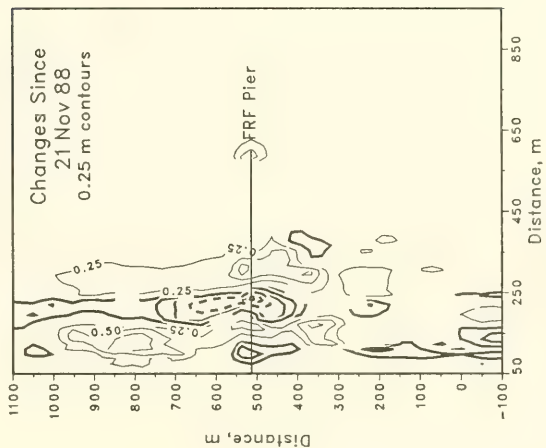
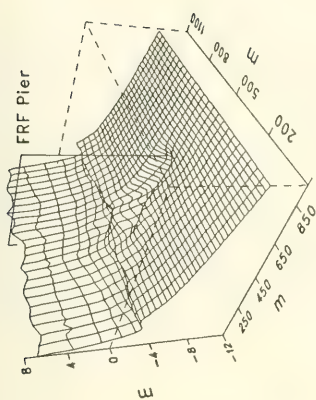


Figure A8. FRF Bathymetry 19 December 88 (depths relative to NGVD)



## APPENDIX B: WAVE DATA FOR GAGE 630

1. Wave data summaries for Gage 630 are presented for 1988 and for 1980 through 1988 in the following forms:

### Daily $H_{mo}$ and $T_p$

2. Figure B1 displays the individual wave height and peak spectral wave period values along with the monthly mean values.

### Joint Distributions of $H_{mo}$ and $T_p$

3. Annual and monthly joint distributions tables are presented in Tables B1 and B2, and data for 1980 through 1988 are in Tables B3 and B4. Each table gives the frequency (in parts per 10,000) for which the wave height and peak period were within the specified intervals; these values can be converted to percent by dividing by 100. Marginal totals are also included. The row total gives the total number of observations out of 10,000 which fell within each specified peak period interval. The column total gives the number of observations out of 10,000 which fell within each specified wave height interval.

### Cumulative Distributions of Wave Height

4. Annual and monthly wave height distributions for 1988 are plotted in cumulative form in Figures B2 and B3. Data for 1980 through 1988 are in Figure B4.

### Peak Spectral Wave Period Distributions

5. Annual and monthly peak wave period,  $T_p$ , distribution histograms for 1988 are presented in Figures B5 and B6. Data for 1980 through 1988 are in Figure B7.

### Persistence of Wave Heights

6. Table B5 shows the number of times in 1988 when the specified wave height was equaled or exceeded at least once during each day for the duration (consecutive days). Data for 1980 through 1988 are given in Table B6. An example is shown below:

| Height<br>m | Consecutive Day(s) or Longer |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |
|-------------|------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
|             | 1                            | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19+ |
| 0.5         | 18                           | 15 |    | 14 | 13 | 12 |    | 11 | 10 | 9  |    |    |    | 8  |    | 7  |    |    |     |
| 1.0         | 50                           | 34 | 24 | 21 | 18 | 14 | 12 | 8  | 7  | 3  |    |    | 2  |    |    |    |    |    |     |
| 1.5         | 41                           | 19 | 8  | 6  | 2  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |     |
| 2.0         | 22                           | 9  |    | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |
| 2.5         | 10                           | 5  | 2  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |
| 3.0         | 6                            | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |
| 3.5         |                              | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |
| 4.0         | 1                            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |

This example indicates that wave heights equaled or exceeded 1.0 m 50 times for at least 1 day; 34 times for at least 2 days; 24 times for at least 3 days, etc. Therefore, on 16 occasions the height equaled or exceeded 1.0 m for 1 day exactly ( $50 - 34 = 16$ ); on 10 occasions for 2 days; on 3 occasions for 3 days, etc. Note that the height exceeded 1 m 50 times for 1 day or longer, while heights exceeded 0.5 m only 18 times for this same duration. This change in durations occurred because the longer durations of lower waves may be interspersed with shorter, but more frequent, intervals of higher waves. For example, one of the times that the wave heights exceeded 0.5 m for 16 days may have represented 3 times the height exceeded 1 m for shorter durations.

### Spectra

7. Monthly spectra for the offshore Waverider buoy (Gage 630) are presented in Figure B8. The plots show "relative" energy density as a function of wave frequency. These figures summarize the large number of spectra for each month. The figures emphasize the higher energy density associated with storms as well as the general shifts in energy density to different frequencies. As used here, "relative" indicates the spectra have been smoothed by the three-dimensional surface drawing routine. Consequently, extremely high- and low-energy density values are modified to produce a smooth

surface. The figures are not intended for quantitative measurements; however, they do provide the energy density as a function of frequency relative to the other spectra for the month.

8. Monthly and annual wave statistics for Gage 630 for 1988 and for 1980 through 1988 are presented in Table B7.

9. Figure B9 plots monthly time histories of wave height and period.



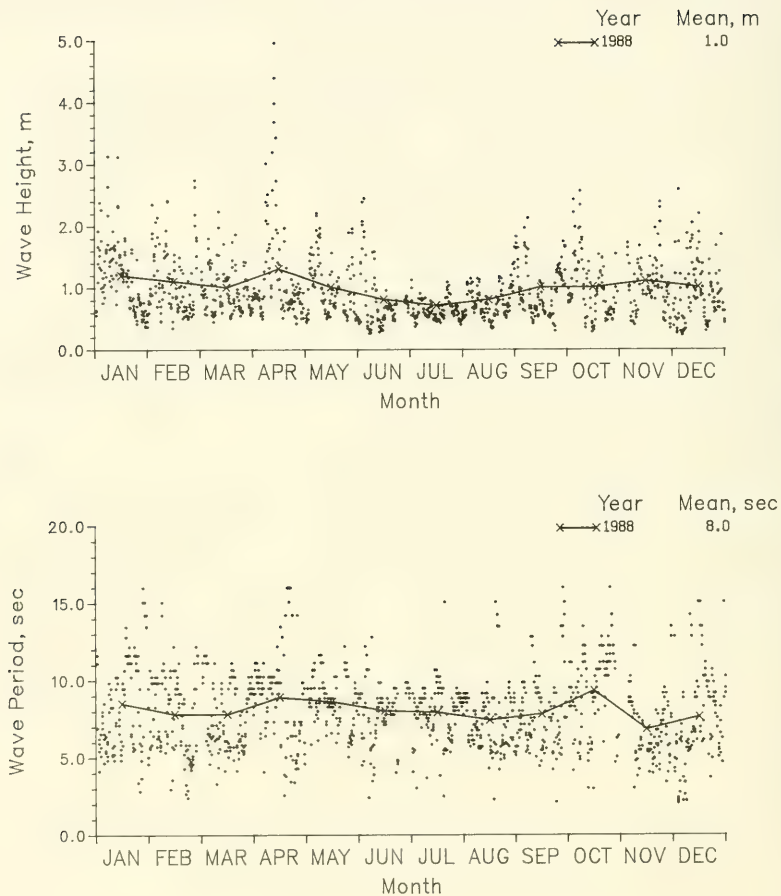


Figure B1. 1988 daily wave height and period values with monthly means for Gage 630

Table B1  
Annual Joint Distribution of  $H_{mo}$  versus  $T_p$

| Height(m)      | Annual 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |               |               |               |                 | Total |
|----------------|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
|                | Period(sec)  |             |             |             |             |             |             |             |               |               |               |                 |       |
|                | 2.0-<br>2.9  | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
| 0.00 - 0.49    | 88   | 22          | 22          | 103         | 22          | 96          | 301         | 301         | 103           | 44            | 103           | .               | 1205  |
| 0.50 - 0.99    | 66   | 147         | 301         | 662         | 551         | 610         | 1051        | 904         | 662           | 118           | 191           | .               | 5263  |
| 1.00 - 1.49    | .  | .           | 184         | 515         | 456         | 221         | 206         | 199         | 272           | 29            | 118           | .               | 2200  |
| 1.50 - 1.99    | .  | .           | 22          | 265         | 199         | 74          | 110         | 74          | 154           | 22            | 37            | .               | 957   |
| 2.00 - 2.49    | .  | .           | .           | 29          | 81          | 44          | 51          | 15          | 22            | .             | 7             | .               | 249   |
| 2.50 - 2.99    | .  | .           | .           | 7           | 22          | 7           | 7           | 15          | .             | .             | 7             | .               | 58    |
| 3.00 - 3.49    | .  | .           | .           | .           | .           | 22          | 7           | 7           | .             | .             | .             | .               | 36    |
| 3.50 - 3.99    | .  | .           | .           | .           | .           | .           | 15          | .           | .             | .             | .             | .               | 15    |
| 4.00 - 4.49    | .  | .           | .           | .           | .           | .           | .           | 7           | .             | .             | .             | .               | 7     |
| 4.50 - 4.99    | .  | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 7     |
| 5.00 - Greater | .  | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| Total          | 154  | 169         | 529         | 1581        | 1331        | 1074        | 1748        | 1522        | 1213          | 213           | 463           | 0               |       |

Table B2  
Monthly Joint Distribution of  $H_{mo}$  versus  $T_p$

| Height(m)      | January 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |               |               |               |                 | Total |
|----------------|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
|                | Period(sec)   |             |             |             |             |             |             |             |               |               |               |                 |       |
|                | 2.0-<br>2.9   | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
|                |   |             |             |             |             |             |             |             |               |               |               |                 |       |
| 0.00 - 0.49    | .   | .           | .           | 81          | .           | .           | 81          | .           | 161           | 242           | 242           | .               | 807   |
| 0.50 - 0.99    | 81  | 161         | 242         | 403         | 403         | 161         | 161         | 242         | 887           | 242           | 242           | .               | 3225  |
| 1.00 - 1.49    | .   | .           | 242         | 484         | 565         | 81          | 323         | 565         | 806           | .             | 81            | .               | 3147  |
| 1.50 - 1.99    | .   | .           | 81          | 1048        | 161         | 161         | 81          | 242         | 161           | 81            | 161           | .               | 2177  |
| 2.00 - 2.49    | .   | .           | .           | .           | 161         | 161         | .           | 81          | .             | .             | .             | .               | 403   |
| 2.50 - 2.99    | .   | .           | .           | .           | 81          | .           | .           | .           | .             | .             | .             | .               | 81    |
| 3.00 - 3.49    | .   | .           | .           | .           | .           | 81          | 81          | .           | .             | .             | .             | .               | 162   |
| 3.50 - 3.99    | .   | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.00 - 4.49    | .   | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.50 - 4.99    | .   | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 5.00 - Greater | .   | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| Total          | 81  | 161         | 565         | 2016        | 1371        | 645         | 727         | 1130        | 2015          | 565           | 726           | 0               |       |

| February 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | .           | .           | .           | 86          | .           | .           | .           | .           | 86            | 86            | 172           | .               | 430  |       |
| 0.50 - 0.99  | 345         | 172         | 603         | 948         | 172         | 86          | 690         | 1121        | 776           | .             | .             | .               | 4913 |       |
| 1.00 - 1.49  | .           | .           | 259         | 517         | 259         | 259         | 172         | 259         | 690           | .             | .             | .               | 2415 |       |
| 1.50 - 1.99  | .           | .           | .           | 172         | 517         | 172         | 259         | 86          | 259           | .             | .             | .               | 1465 |       |
| 2.00 - 2.49  | .           | .           | .           | 172         | 172         | .           | 86          | 86          | .             | .             | 86            | .               | 602  |       |
| 2.50 - 2.99  | .           | .           | .           | 86          | .           | .           | .           | 86          | .             | .             | .             | .               | 172  |       |
| 3.00 - 3.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 345         | 172         | 862         | 1981        | 1120        | 517         | 1207        | 1638        | 1811          | 86            | 258           | 0               |      |       |

| March 1988, Gage 630                          |             |             |             |             |             |             |             |             |               |               |               |                 |       |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
| 0.00 - 0.49                                   | .           | .           | .           | .           | .           | .           | 83          | .           | .             | .             | .             | .               | 83    |
| 0.50 - 0.99                                   | .           | 83          | 83          | 826         | 1074        | 413         | 579         | 1736        | 1488          | .             | .             | .               | 6282  |
| 1.00 - 1.49                                   | .           | .           | 331         | 661         | 661         | 413         | 331         | 165         | 331           | .             | .             | .               | 2893  |
| 1.50 - 1.99                                   | .           | .           | 83          | 331         | 165         | 83          | .           | .           | .             | .             | .             | .               | 662   |
| 2.00 - 2.49                                   | .           | .           | .           | 83          | .           | .           | .           | .           | .             | .             | .             | .               | 83    |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| Total   | 0           | 83          | 497         | 1901        | 1900        | 909         | 993         | 1901        | 1819          | 0             | 0             | 0               |       |

(Continued)

(Sheet 1 of 4)

Table B2 (Continued)

| April 1988, Gage 630                          |             |             |             |             |             |             |             |             |               |               |               |                 |       |  |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|--|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |  |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |  |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |  |
| 0.00 - 0.49                                   | .           | .           | .           | .           | .           | .           | .           | 172         | .             | 86            | .             | .               | 258   |  |
| 0.50 - 0.99                                   | 86          | 345         | 603         | 345         | 690         | 603         | 86          | 1293        | 1034          | 345           | 776           | .               | 6206  |  |
| 1.00 - 1.49                                   | .           | .           | .           | 172         | 259         | 259         | 86          | 517         | 172           | .             | .             | .               | 1465  |  |
| 1.50 - 1.99                                   | .           | .           | .           | 172         | .           | 86          | .           | 172         | 345           | .             | .             | .               | 775   |  |
| 2.00 - 2.49                                   | .           | .           | .           | .           | .           | .           | 172         | .           | 259           | .             | .             | .               | 431   |  |
| 2.50 - 2.99                                   | .           | .           | .           | .           | 86          | .           | .           | 86          | .             | .             | 86            | .               | 258   |  |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | 172         | .           | 86          | .             | .             | .             | .               | 258   |  |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | 172         | .           | .             | .             | .             | .               | 172   |  |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | 86          | .           | .             | .             | .             | .               | 86    |  |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | 86          | .             | .             | .             | .               | 86    |  |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| Total   | 86          | 345         | 603         | 689         | 1035        | 1120        | 602         | 2412        | 1810          | 431           | 862           | 0               |       |  |

| May 1988, Gage 630                            |             |             |             |             |             |             |             |             |               |               |               |                 |       |  |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|--|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |  |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |  |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |  |
| 0.00 - 0.49                                   | .           | .           | .           | 90          | .           | .           | 450         | 270         | .             | .             | .             | .               | 810   |  |
| 0.50 - 0.99                                   | .           | .           | .           | 270         | 360         | 631         | 1802        | 1261        | 721           | .             | 90            | .               | 5135  |  |
| 1.00 - 1.49                                   | .           | .           | .           | 270         | 270         | 450         | 721         | 180         | 541           | .             | .             | .               | 2432  |  |
| 1.50 - 1.99                                   | .           | .           | .           | .           | 180         | 180         | 360         | 180         | 541           | .             | .             | .               | 1441  |  |
| 2.00 - 2.49                                   | .           | .           | .           | 90          | 90          | .           | .           | .           | .             | .             | .             | .               | 180   |  |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| Total   | 0           | 0           | 0           | 630         | 900         | 1351        | 3333        | 1891        | 1803          | 0             | 90            | 0               |       |  |

| June 1988, Gage 630                           |             |             |             |             |             |             |             |             |               |               |               |                 |       |  |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|--|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |  |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |  |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |  |
| 0.00 - 0.49                                   | 99          | 99          | 99          | 297         | 99          | 693         | 891         | 792         | .             | .             | 198           | .               | 3267  |  |
| 0.50 - 0.99                                   | .           | 198         | 495         | .           | 396         | 990         | 1980        | 990         | 297           | .             | .             | .               | 4950  |  |
| 1.00 - 1.49                                   | .           | .           | 99          | .           | 99          | 99          | .           | .           | 99            | .             | .             | .               | 693   |  |
| 1.50 - 1.99                                   | .           | .           | 99          | 99          | 99          | .           | .           | .           | 198           | .             | 99            | .               | 594   |  |
| 2.00 - 2.49                                   | .           | .           | .           | .           | 99          | 99          | 297         | .           | .             | .             | .             | .               | 495   |  |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |  |
| Total   | 99          | 297         | 792         | 396         | 693         | 1881        | 3168        | 1782        | 594           | 0             | 297           | 0               |       |  |

(Continued)

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Table B2 (Continued)

| July 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | .           | .           | .           | 83          | .           | 165         | 909         | 744         | 248           | .             | .             | .               | 2149 |       |
| 0.50 - 0.99  | 83          | 248         | 83          | 826         | 1074        | 1405        | 2562        | 992         | 165           | .             | 83            | .               | 7521 |       |
| 1.00 - 1.49  | .           | .           | .           | 83          | 248         | .           | .           | .           | .             | .             | .             | .               | 331  |       |
| 1.50 - 1.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 2.00 - 2.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 2.50 - 2.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.00 - 3.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 83          | 248         | 83          | 992         | 1322        | 1570        | 3471        | 1736        | 413           | 0             | 83            | 0               |      |       |

| August 1988, Gage 630                         |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49                                   | 84          | .           | 84          | 336         | 84          | .           | 336         | 84          | .             | .             | .             | .               | 1008 |       |
| 0.50 - 0.99                                   | .           | .           | 252         | 1092        | 1092        | 1261        | 2101        | 756         | .             | 336           | 84            | .               | 6974 |       |
| 1.00 - 1.49                                   | .           | .           | 84          | 1008        | 588         | .           | 168         | 84          | .             | .             | .             | .               | 1932 |       |
| 1.50 - 1.99                                   | .           | .           | .           | 84          | .           | .           | .           | .           | .             | .             | .             | .               | 84   |       |
| 2.00 - 2.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total   | 84          | 0           | 420         | 2520        | 1764        | 1261        | 2605        | 924         | 0             | 336           | 84            | 0               |      |       |

| September 1988, Gage 630                      |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49                                   | 90          | .           | .           | .           | 90          | .           | 90          | 360         | 90            | .             | .             | .               | 720  |       |
| 0.50 - 0.99                                   | .           | .           | 270         | 1171        | 450         | 991         | 721         | 1081        | 180           | .             | 360           | .               | 5224 |       |
| 1.00 - 1.49                                   | .           | .           | 90          | 631         | 721         | 360         | 270         | .           | 90            | 270           | 360           | .               | 2792 |       |
| 1.50 - 1.99                                   | .           | .           | .           | 450         | 450         | 90          | 180         | .           | .             | .             | .             | .               | 1170 |       |
| 2.00 - 2.49                                   | .           | .           | .           | .           | 90          | .           | .           | .           | .             | .             | .             | .               | 90   |       |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total   | 90          | 0           | 360         | 2252        | 1801        | 1441        | 1261        | 1441        | 360           | 270           | 720           | 0               |      |       |

(Continued)

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Table B2 (Concluded)

| October 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)   | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49   | 93          | .           | .           | .           | .           | 93          | 278         | 278         | 556           | .             | 278           | .               | 1576 |       |
| 0.50 - 0.99   | 93          | .           | 93          | 370         | 185         | .           | 648         | 648         | 1759          | 278           | 278           | .               | 4352 |       |
| 1.00 - 1.49   | .           | .           | 278         | 648         | 93          | .           | 93          | 278         | 278           | .             | 833           | .               | 2501 |       |
| 1.50 - 1.99   | .           | .           | .           | 185         | 185         | .           | 278         | 93          | 370           | 93            | .             | .               | 1204 |       |
| 2.00 - 2.49   | .           | .           | .           | .           | 93          | 93          | 93          | .           | .             | .             | .             | .               | 279  |       |
| 2.50 - 2.99   | .           | .           | .           | .           | 93          | .           | .           | .           | .             | .             | .             | .               | 93   |       |
| 3.00 - 3.49   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total   | 186         | 0           | 371         | 1203        | 649         | 186         | 1390        | 1297        | 2963          | 371           | 1389          | 0               |      |       |

| November 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | .           | .           | .           | .           | .           | 319         | 319         | 213         | .             | 106           | 319           | .               | 1276 |       |
| 0.50 - 0.99  | 106         | 319         | 532         | 1064        | 532         | 532         | 638         | 106         | .             | .             | .             | .               | 3829 |       |
| 1.00 - 1.49  | .           | .           | 851         | 1383        | 532         | 532         | 213         | 213         | 106           | .             | .             | .               | 3830 |       |
| 1.50 - 1.99  | .           | .           | .           | 106         | 213         | 106         | 213         | 106         | .             | .             | .             | .               | 744  |       |
| 2.00 - 2.49  | .           | .           | .           | 106         | 106         | 106         | .           | .           | .             | .             | .             | .               | 318  |       |
| 2.50 - 2.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.00 - 3.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 106         | 319         | 1383        | 2659        | 1383        | 1595        | 1383        | 638         | 106           | 106           | 319           | 0               |      |       |

| December 1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | 678         | 169         | 85          | 254         | .           | .           | 254         | 763         | 85            | .             | 85            | .               | 2373 |       |
| 0.50 - 0.99  | .           | 254         | 424         | 593         | 424         | 254         | 678         | 508         | 508           | 169           | 339           | .               | 4151 |       |
| 1.00 - 1.49  | .           | .           | 85          | 424         | 847         | 254         | 85          | 85          | 85            | 85            | 169           | .               | 2119 |       |
| 1.50 - 1.99  | .           | .           | .           | 424         | 424         | .           | .           | .           | .             | 85            | 169           | .               | 1102 |       |
| 2.00 - 2.49  | .           | .           | .           | .           | 169         | .           | .           | .           | .             | .             | .             | .               | 169  |       |
| 2.50 - 2.99  | .           | .           | .           | .           | .           | 85          | .           | .           | .             | .             | .             | .               | 85   |       |
| 3.00 - 3.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 678         | 423         | 594         | 1695        | 1864        | 593         | 1017        | 1356        | 678           | 339           | 762           | 0               |      |       |

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Table B3  
Annual Joint Distribution of  $H_{mo}$  versus  $T_p$  (All Years)

| Height(m)      | Annual 1980-1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |               |               |               |                 | Total |
|----------------|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
|                | Period(sec)   |             |             |             |             |             |             |             |               |               |               |                 |       |
|                | 2.0-<br>2.9   | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
|                |   |             |             |             |             |             |             |             |               |               |               |                 |       |
| 0.00 - 0.49    | 28  | 18          | 28          | 62          | 94          | 115         | 328         | 281         | 200           | 76            | 134           | 4               | 1368  |
| 0.50 - 0.99    | 39  | 128         | 254         | 499         | 572         | 515         | 860         | 717         | 812           | 151           | 213           | 15              | 4775  |
| 1.00 - 1.49    | .   | 10          | 134         | 402         | 451         | 264         | 246         | 200         | 360           | 39            | 132           | 4               | 2242  |
| 1.50 - 1.99    | .   | .           | 13          | 156         | 256         | 109         | 79          | 70          | 139           | 35            | 77            | 4               | 938   |
| 2.00 - 2.49    | .   | .           | 2           | 26          | 78          | 74          | 49          | 41          | 70            | 29            | 41            | 2               | 412   |
| 2.50 - 2.99    | .   | .           | .           | 1           | 9           | 32          | 17          | 16          | 38            | 11            | 23            | .               | 147   |
| 3.00 - 3.49    | .   | .           | .           | .           | 1           | 9           | 15          | 14          | 17            | 4             | 9             | .               | 69    |
| 3.50 - 3.99    | .   | .           | .           | .           | .           | 1           | 5           | 7           | 10            | 4             | 4             | .               | 31    |
| 4.00 - 4.49    | .   | .           | .           | .           | .           | .           | 2           | 2           | 7             | 1             | 2             | .               | 14    |
| 4.50 - 4.99    | .   | .           | .           | .           | .           | .           | .           | 1           | 3             | .             | .             | .               | 4     |
| 5.00 - Greater | .   | .           | .           | .           | .           | .           | 1           | .           | .             | 2             | 1             | .               | 4     |
| Total          | 67  | 156         | 431         | 1146        | 1461        | 1119        | 1602        | 1349        | 1656          | 352           | 636           | 29              |       |



Table B4

Monthly Joint Distribution of  $H_{mo}$  versus  $T_p$  (All Years)

| January 1980-1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | 105         | 11          | .           | 105         | 84          | 32          | 168         | 84          | 221           | 63            | 105           | .               | 978  |       |
| 0.50 - 0.99  | 74          | 232         | 253         | 368         | 389         | 347         | 305         | 495         | 874           | 116           | 253           | .               | 3706 |       |
| 1.00 - 1.49  | .           | 21          | 168         | 505         | 558         | 221         | 168         | 179         | 589           | .             | 74            | 11              | 2494 |       |
| 1.50 - 1.99  | .           | .           | 32          | 379         | 463         | 232         | 95          | 116         | 242           | 21            | 63            | .               | 1643 |       |
| 2.00 - 2.49  | .           | .           | .           | 32          | 189         | 221         | 95          | 32          | 126           | 42            | 32            | 11              | 780  |       |
| 2.50 - 2.99  | .           | .           | .           | .           | 21          | 84          | 53          | 21          | 42            | 21            | 53            | .               | 295  |       |
| 3.00 - 3.49  | .           | .           | .           | .           | .           | 11          | 32          | 11          | 32            | .             | .             | .               | 86   |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | .           | .           | 11            | .             | .             | .               | 11   |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | .           | 11            | .             | .             | .               | 11   |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 179         | 264         | 453         | 1389        | 1704        | 1148        | 916         | 938         | 2148          | 263           | 580           | 22              |      |       |

| February 1980-1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)   | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49   | .           | .           | .           | 22          | 33          | 22          | 88          | .           | 44            | 33            | 133           | .               | 375  |       |
| 0.50 - 0.99   | 66          | 77          | 155         | 453         | 453         | 243         | 541         | 685         | 1116          | 22            | 144           | 11              | 3966 |       |
| 1.00 - 1.49   | .           | 11          | 110         | 619         | 652         | 232         | 298         | 354         | 608           | 88            | 221           | .               | 3193 |       |
| 1.50 - 1.99   | .           | .           | 11          | 188         | 365         | 199         | 110         | 99          | 221           | 66            | 110           | .               | 1369 |       |
| 2.00 - 2.49   | .           | .           | .           | 99          | 122         | 22          | 44          | 88          | 99            | 55            | 110           | .               | 639  |       |
| 2.50 - 2.99   | .           | .           | .           | 11          | 11          | 33          | .           | 11          | 122           | 22            | 66            | .               | 276  |       |
| 3.00 - 3.49   | .           | .           | .           | .           | .           | 11          | .           | 22          | 33            | 11            | 22            | .               | 99   |       |
| 3.50 - 3.99   | .           | .           | .           | .           | .           | .           | .           | 11          | 11            | .             | .             | .               | 22   |       |
| 4.00 - 4.49   | .           | .           | .           | .           | .           | .           | .           | 11          | 33            | .             | .             | .               | 44   |       |
| 4.50 - 4.99   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater  | .           | .           | .           | .           | .           | .           | 11          | .           | .             | .             | .             | .               | 11   |       |
| Total   | 66          | 88          | 276         | 1392        | 1636        | 762         | 1092        | 1281        | 2287          | 297           | 806           | 11              |      |       |

| March 1980-1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | 10          | .           | .           | 10          | 50          | 50          | 80          | 40          | 120           | 60            | 60            | .               | 480  |       |
| 0.50 - 0.99  | 10          | 90          | 190         | 421         | 511         | 421         | 521         | 772         | 872           | 150           | 180           | .               | 4138 |       |
| 1.00 - 1.49  | .           | 10          | 210         | 411         | 541         | 341         | 281         | 301         | 711           | 60            | 331           | .               | 3197 |       |
| 1.50 - 1.99  | .           | .           | 10          | 240         | 230         | 100         | 80          | 100         | 251           | 90            | 140           | .               | 1241 |       |
| 2.00 - 2.49  | .           | .           | .           | 20          | 50          | 30          | 70          | 50          | 160           | 40            | 110           | .               | 530  |       |
| 2.50 - 2.99  | .           | .           | .           | .           | 20          | 10          | 10          | 10          | 60            | 20            | 50            | .               | 180  |       |
| 3.00 - 3.49  | .           | .           | .           | .           | 10          | .           | 10          | 20          | 50            | 10            | 10            | .               | 110  |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | .           | .           | 20          | 20            | .             | 10            | .               | 50   |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | 10          | 10          | 10            | .             | 20            | .               | 50   |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | .           | 20            | .             | .             | .               | 20   |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 20          | 100         | 410         | 1102        | 1412        | 952         | 1062        | 1323        | 2274          | 430           | 911           | 0               |      |       |

(Continued)

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Table B4 (Continued)

| April 1980-1988, Gage 630<br>Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Height(m)  | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|  | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49  | .           | 10          | 21          | 21          | 31          | 21          | 308         | 226         | 185           | 103           | 103           | .               | 1029 |       |
| 0.50 - 0.99  | 92          | 195         | 267         | 390         | 503         | 513         | 677         | 697         | 1128          | 287           | 421           | .               | 5170 |       |
| 1.00 - 1.49  | .           | 10          | 103         | 226         | 369         | 318         | 328         | 287         | 369           | 62            | 154           | .               | 2226 |       |
| 1.50 - 1.99  | .           | .           | .           | 144         | 123         | 92          | 92          | 113         | 215           | 31            | 113           | .               | 923  |       |
| 2.00 - 2.49  | .           | .           | .           | 41          | 31          | 10          | 51          | 62          | 62            | 31            | 10            | .               | 298  |       |
| 2.50 - 2.99  | .           | .           | .           | .           | 10          | 21          | 31          | 21          | 41            | 31            | 21            | .               | 176  |       |
| 3.00 - 3.49  | .           | .           | .           | .           | .           | 31          | 21          | 31          | 31            | .             | .             | .               | 114  |       |
| 3.50 - 3.99  | .           | .           | .           | .           | .           | 10          | 41          | .           | .             | .             | .             | .               | 51   |       |
| 4.00 - 4.49  | .           | .           | .           | .           | .           | .           | 10          | .           | .             | .             | .             | .               | 10   |       |
| 4.50 - 4.99  | .           | .           | .           | .           | .           | .           | .           | 10          | .             | .             | .             | .               | 10   |       |
| 5.00 - Greater   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total  | 92          | 215         | 391         | 822         | 1067        | 1016        | 1559        | 1447        | 2031          | 545           | 822           | 0               |      |       |

| May 1980-1988, Gage 630                       |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49                                   | 10          | 20          | 31          | 92          | 132         | 163         | 448         | 254         | 153           | 20            | 61            | .               | 1384 |       |
| 0.50 - 0.99                                   | 20          | 153         | 326         | 621         | 560         | 712         | 1312        | 1099        | 712           | 31            | 163           | .               | 5709 |       |
| 1.00 - 1.49                                   | .           | .           | 92          | 234         | 336         | 224         | 448         | 193         | 336           | 10            | 92            | .               | 1965 |       |
| 1.50 - 1.99                                   | .           | .           | 10          | 51          | 92          | 41          | 132         | 81          | 122           | 31            | 71            | .               | 631  |       |
| 2.00 - 2.49                                   | .           | .           | .           | 20          | 20          | 61          | .           | 41          | 10            | 31            | 31            | .               | 214  |       |
| 2.50 - 2.99                                   | .           | .           | .           | .           | 10          | 10          | 10          | 10          | 10            | 20            | 10            | .               | 80   |       |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | 10            | 10            | .             | .               | 20   |       |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total   | 30          | 173         | 459         | 1018        | 1150        | 1211        | 2350        | 1678        | 1343          | 153           | 438           | 0               |      |       |

| June 1980-1988, Gage 630                      |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49                                   | 32          | 43          | 65          | 119         | 227         | 378         | 636         | 583         | 205           | 43            | 32            | .               | 2363 |       |
| 0.50 - 0.99                                   | 54          | 237         | 378         | 658         | 658         | 734         | 1650        | 895         | 572           | 173           | 32            | .               | 6041 |       |
| 1.00 - 1.49                                   | .           | .           | 76          | 205         | 227         | 194         | 194         | 108         | 108           | .             | 54            | .               | 1166 |       |
| 1.50 - 1.99                                   | .           | .           | 22          | 54          | 76          | 65          | 22          | 11          | 76            | .             | 11            | .               | 337  |       |
| 2.00 - 2.49                                   | .           | .           | .           | .           | 22          | 22          | 43          | 11          | .             | .             | .             | .               | 98   |       |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total   | 86          | 280         | 541         | 1036        | 1210        | 1393        | 2545        | 1608        | 961           | 216           | 129           | 0               |      |       |

(Continued)

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Table B4 (Continued)

| July 1980-1988, Gage 630                      |             |             |             |             |             |             |             |             |               |               |               |                 |       |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
| 0.00 - 0.49                                   | 11          | 21          | 53          | 105         | 243         | 285         | 1108        | 791         | 327           | 127           | 253           | 21              | 3345  |
| 0.50 - 0.99                                   | 42          | 137         | 316         | 643         | 802         | 781         | 1487        | 918         | 411           | 222           | 74            | 63              | 5896  |
| 1.00 - 1.49                                   | .           | 21          | 53          | 169         | 190         | 84          | 53          | 42          | .             | .             | .             | .               | 612   |
| 1.50 - 1.99                                   | .           | .           | .           | 53          | 11          | 21          | 32          | .           | .             | .             | .             | .               | 117   |
| 2.00 - 2.49                                   | .           | .           | .           | 11          | .           | .           | 11          | .           | .             | .             | .             | .               | 22    |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| Total   | 53          | 179         | 422         | 981         | 1246        | 1171        | 2691        | 1751        | 738           | 349           | 327           | 84              |       |

| August 1980-1988, Gage 630                    |             |             |             |             |             |             |             |             |               |               |               |                 |       |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
| 0.00 - 0.49                                   | 32          | 32          | 74          | 137         | 179         | 211         | 474         | 495         | 369           | 74            | 105           | .               | 2182  |
| 0.50 - 0.99                                   | 32          | 95          | 242         | 643         | 832         | 769         | 1412        | 790         | 537           | 190           | 274           | .               | 5816  |
| 1.00 - 1.49                                   | .           | 11          | 148         | 390         | 285         | 232         | 158         | 105         | 63            | 11            | .             | .               | 1403  |
| 1.50 - 1.99                                   | .           | .           | .           | 63          | 137         | 74          | 32          | 21          | 21            | .             | 32            | .               | 380   |
| 2.00 - 2.49                                   | .           | .           | .           | 21          | 21          | 11          | 21          | .           | 42            | .             | 11            | .               | 127   |
| 2.50 - 2.99                                   | .           | .           | .           | .           | 11          | .           | 21          | .           | 11            | .             | 11            | .               | 54    |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | 11          | 11          | .           | 11            | .             | .             | .               | 33    |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | 11          | .             | .             | .             | .               | 11    |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| Total   | 64          | 138         | 464         | 1254        | 1465        | 1308        | 2129        | 1422        | 1054          | 275           | 433           | 0               |       |

| September 1980-1988, Gage 630                 |             |             |             |             |             |             |             |             |               |               |               |                 |       |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
| 0.00 - 0.49                                   | 10          | 10          | 10          | 31          | 31          | 21          | 94          | 333         | 271           | 125           | 104           | 10              | 1050  |
| 0.50 - 0.99                                   | .           | 52          | 188         | 417         | 583         | 521         | 813         | 802         | 1031          | 146           | 250           | .               | 4803  |
| 1.00 - 1.49                                   | .           | 10          | 83          | 438         | 604         | 354         | 448         | 219         | 354           | 83            | 177           | 10              | 2780  |
| 1.50 - 1.99                                   | .           | .           | 10          | 115         | 302         | 125         | 83          | 115         | 52            | 10            | 73            | .               | 885   |
| 2.00 - 2.49                                   | .           | .           | .           | 31          | 83          | 42          | 21          | 31          | 73            | 31            | 21            | .               | 333   |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | 31          | 21          | 10          | .             | .             | .             | .               | 62    |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | .           | 10          | 10            | 10            | 10            | .               | 40    |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | 10            | 10            | 10            | .               | 30    |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | 10            | .             | .               | 10    |
| Total   | 10          | 72          | 291         | 1032        | 1603        | 1094        | 1480        | 1520        | 1801          | 425           | 645           | 20              |       |

(Continued)

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Table B4 (Concluded)

| October 1980-1988, Gage 630                   |             |             |             |             |             |             |             |             |               |               |               |                 |       |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 | Total |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |       |
| 0.00 - 0.49                                   | 29          | .           | .           | .           | 48          | 67          | 202         | 164         | 260           | 38            | 144           | .               | 952   |
| 0.50 - 0.99                                   | 10          | 38          | 144         | 337         | 404         | 375         | 674         | 481         | 991           | 173           | 318           | 10              | 3955  |
| 1.00 - 1.49                                   | .           | .           | 164         | 597         | 337         | 212         | 135         | 241         | 452           | 87            | 231           | .               | 2456  |
| 1.50 - 1.99                                   | .           | .           | 29          | 192         | 423         | 77          | 77          | 67          | 202           | 96            | 212           | 38              | 1413  |
| 2.00 - 2.49                                   | .           | .           | .           | 10          | 115         | 192         | 58          | 77          | 144           | 48            | 87            | 10              | 741   |
| 2.50 - 2.99                                   | .           | .           | .           | .           | 19          | 125         | 38          | 58          | 48            | 10            | 38            | .               | 336   |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | 38          | 10          | .           | 10            | .             | 29            | .               | 87    |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | 19          | .             | 19            | .             | .               | 38    |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | 19            | .             | .             | .               | 19    |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0     |
| Total   | 39          | 38          | 337         | 1136        | 1346        | 1086        | 1194        | 1107        | 2126          | 471           | 1059          | 58              |       |

| November 1980-1988, Gage 630                  |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49                                   | 12          | 35          | 35          | 23          | 58          | 116         | 186         | 174         | 93            | 70            | 197           | .               | 999  |       |
| 0.50 - 0.99                                   | 35          | 81          | 372         | 569         | 581         | 511         | 476         | 453         | 569           | 151           | 139           | 58              | 3995 |       |
| 1.00 - 1.49                                   | .           | 23          | 267         | 569         | 720         | 453         | 232         | 244         | 325           | 23            | 81            | 35              | 2972 |       |
| 1.50 - 1.99                                   | .           | .           | 23          | 209         | 348         | 197         | 139         | 70          | 128           | 58            | 12            | 12              | 1196 |       |
| 2.00 - 2.49                                   | .           | .           | .           | 35          | 81          | 139         | 151         | 46          | 23            | 23            | 12            | .               | 510  |       |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | 23          | 12          | 23          | 58            | .             | 12            | .               | 128  |       |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | 23          | 58          | .             | 12            | 12            | .               | 105  |       |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | 46            | 23            | 12            | .               | 81   |       |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | 12            | .             | .               | 12   |       |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| Total   | 47          | 139         | 697         | 1405        | 1788        | 1439        | 1219        | 1068        | 1242          | 372           | 477           | 105             |      |       |

| December 1980-1988, Gage 630                  |             |             |             |             |             |             |             |             |               |               |               |                 |      | Total |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-----------------|------|-------|
| Percent Occurrence(X100) of Height and Period |             |             |             |             |             |             |             |             |               |               |               |                 |      |       |
| Height(m)                                     | Period(sec) |             |             |             |             |             |             |             |               |               |               |                 |      |       |
|   | 2.0-<br>2.9 | 3.0-<br>3.9 | 4.0-<br>4.9 | 5.0-<br>5.9 | 6.0-<br>6.9 | 7.0-<br>7.9 | 8.0-<br>8.9 | 9.0-<br>9.9 | 10.0-<br>11.9 | 12.0-<br>13.9 | 14.0-<br>15.9 | 16.0-<br>Longer |      |       |
| 0.00 - 0.49                                   | 90          | 34          | 56          | 79          | 11          | 23          | 135         | 237         | 135           | 158           | 327           | 11              | 1296 |       |
| 0.50 - 0.99                                   | 34          | 158         | 237         | 496         | 609         | 237         | 417         | 485         | 891           | 147           | 293           | 45              | 4049 |       |
| 1.00 - 1.49                                   | .           | .           | 147         | 474         | 643         | 327         | 203         | 124         | 383           | 34            | 147           | .               | 2482 |       |
| 1.50 - 1.99                                   | .           | .           | 11          | 180         | 519         | 101         | 56          | 45          | 124           | 11            | 68            | .               | 1115 |       |
| 2.00 - 2.49                                   | .           | .           | 23          | .           | 214         | 135         | 34          | 56          | 90            | 45            | 68            | .               | 665  |       |
| 2.50 - 2.99                                   | .           | .           | .           | .           | .           | 34          | .           | 23          | 68            | .             | 11            | .               | 136  |       |
| 3.00 - 3.49                                   | .           | .           | .           | .           | .           | .           | 79          | 23          | 23            | .             | 11            | .               | 136  |       |
| 3.50 - 3.99                                   | .           | .           | .           | .           | .           | .           | 23          | 23          | 34            | .             | 11            | .               | 91   |       |
| 4.00 - 4.49                                   | .           | .           | .           | .           | .           | .           | .           | .           | 11            | .             | .             | .               | 11   |       |
| 4.50 - 4.99                                   | .           | .           | .           | .           | .           | .           | .           | .           | .             | .             | .             | .               | 0    |       |
| 5.00 - Greater                                | .           | .           | .           | .           | .           | .           | .           | .           | .             | 11            | 11            | .               | 22   |       |
| Total   | 124         | 192         | 474         | 1229        | 1996        | 857         | 947         | 1016        | 1759          | 406           | 947           | 56              |      |       |

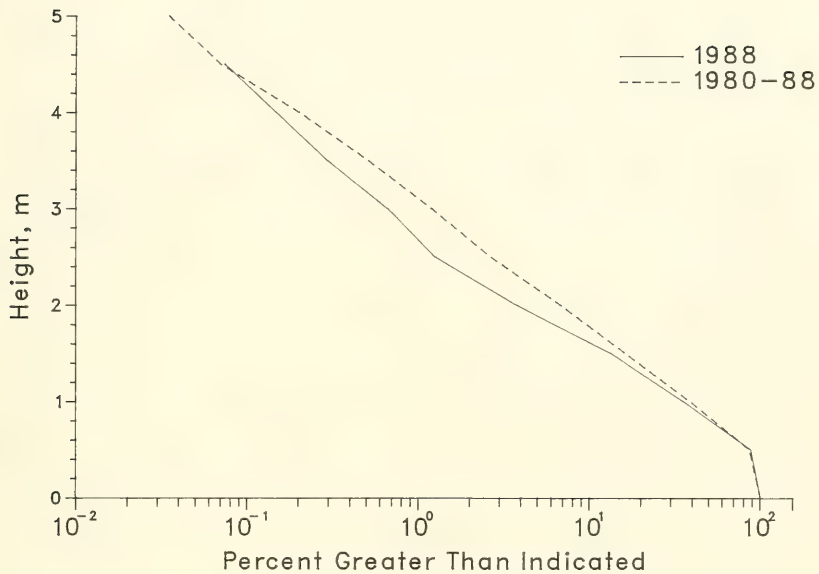


Figure B2. Annual cumulative wave height distributions  
for Gage 630

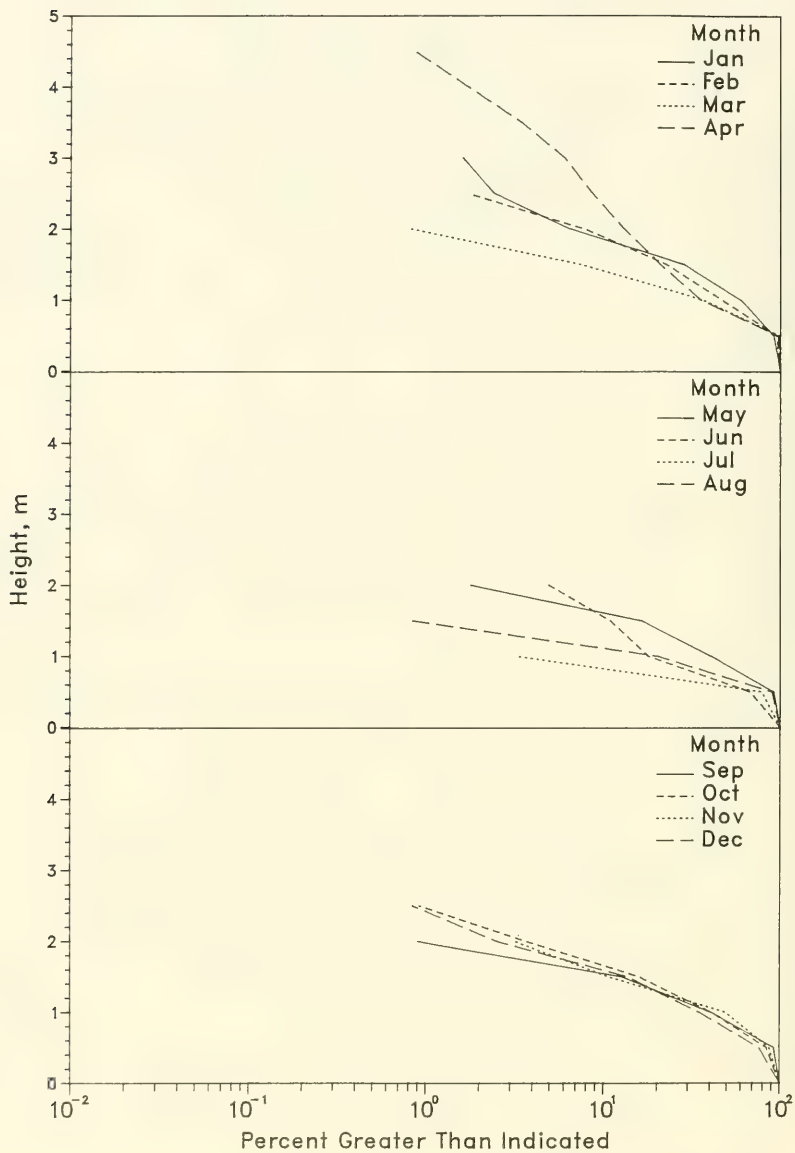


Figure B3. 1988 monthly wave height distributions  
for Gage 630

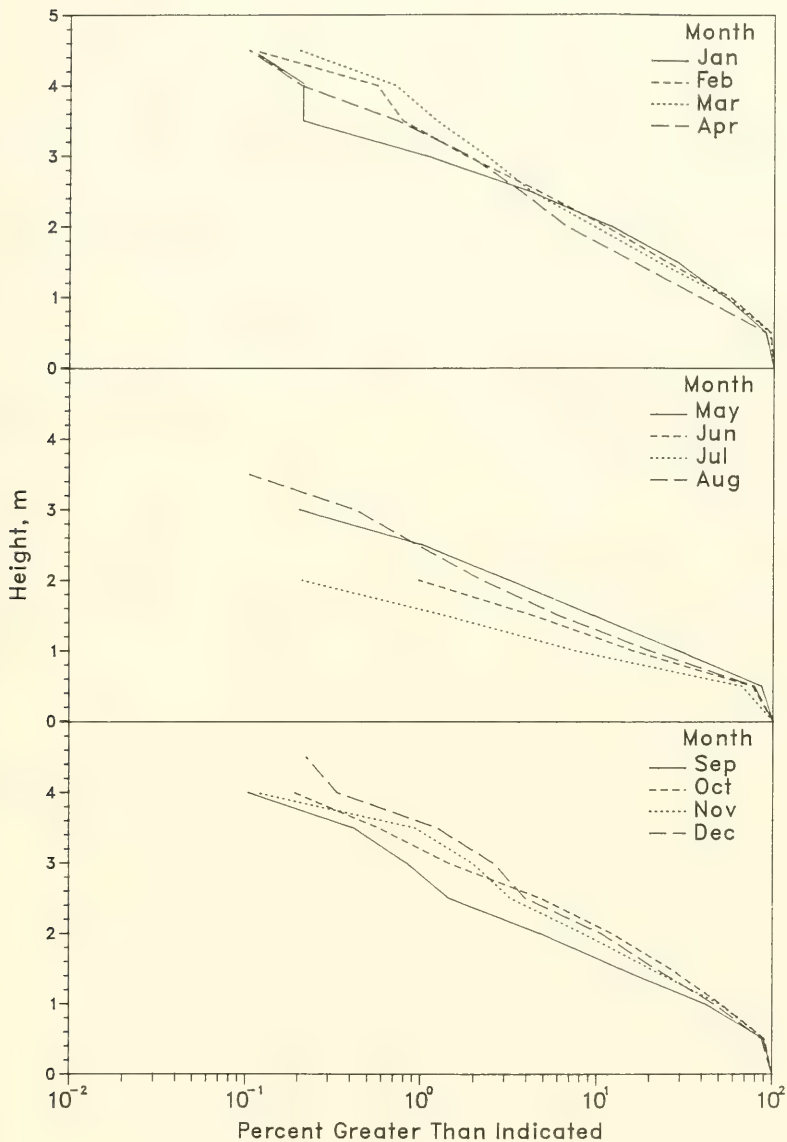


Figure B4. 1980-1988 monthly wave height distributions  
for Gage 630



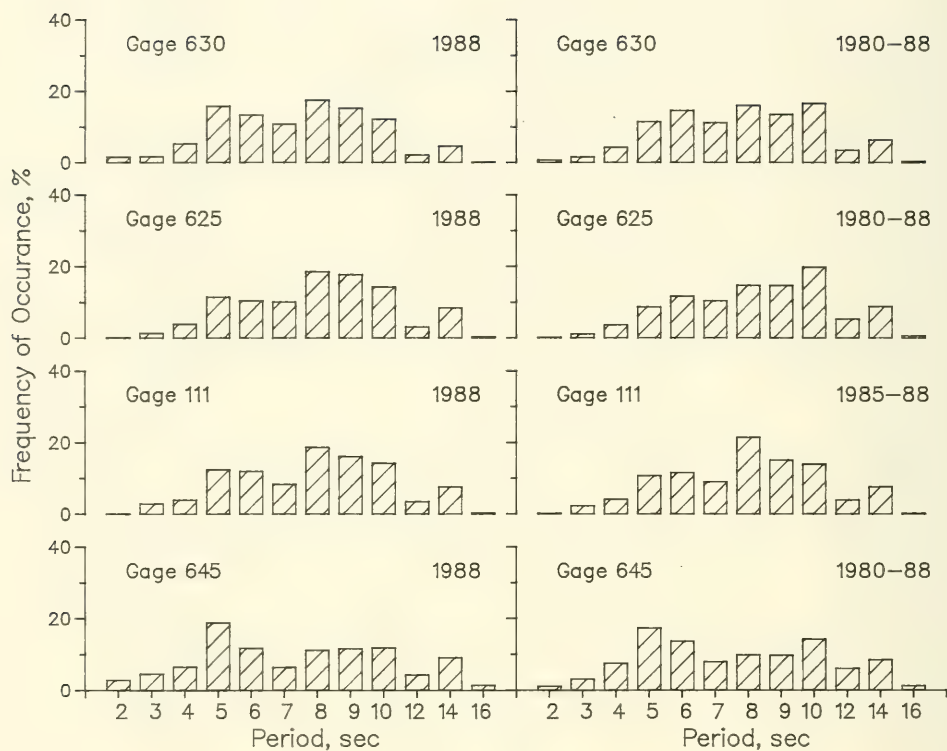


Figure B5. Annual wave period distributions for all gages

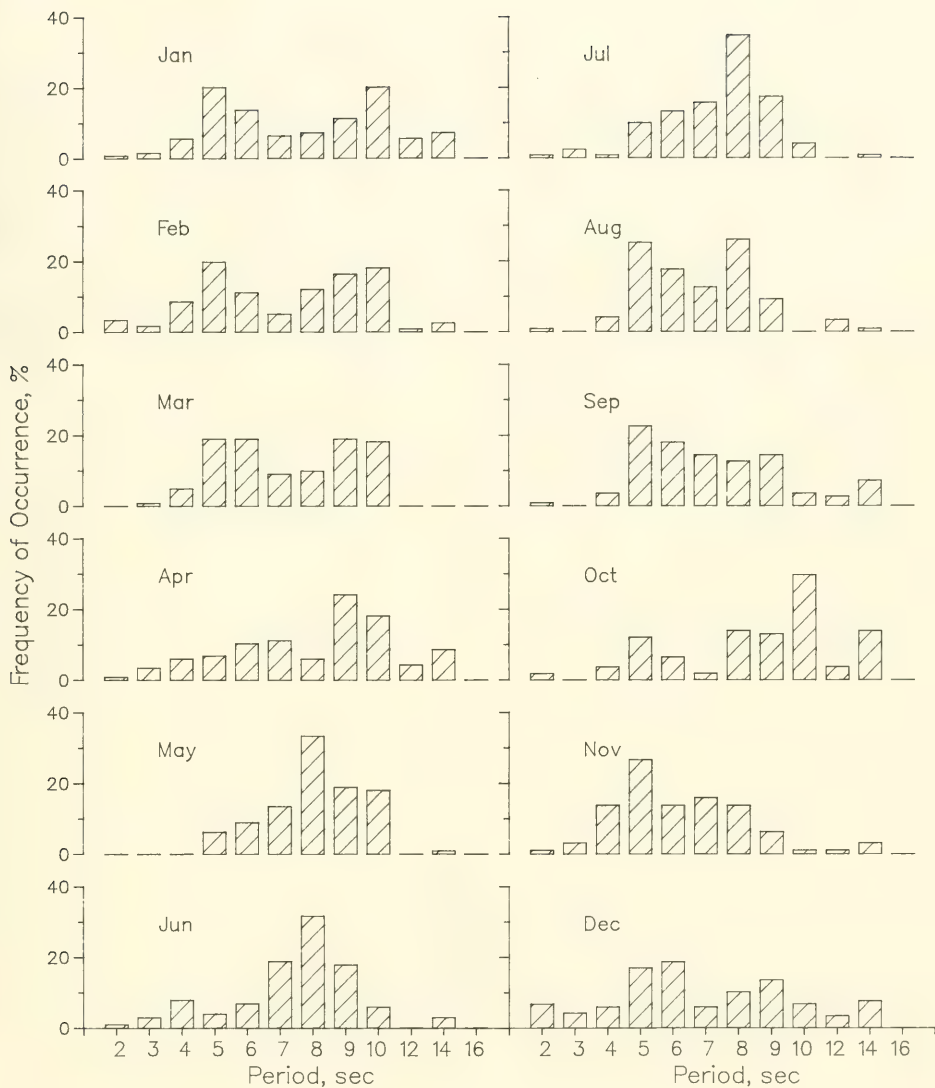


Figure B6. 1988 monthly wave period distributions for Gage 630

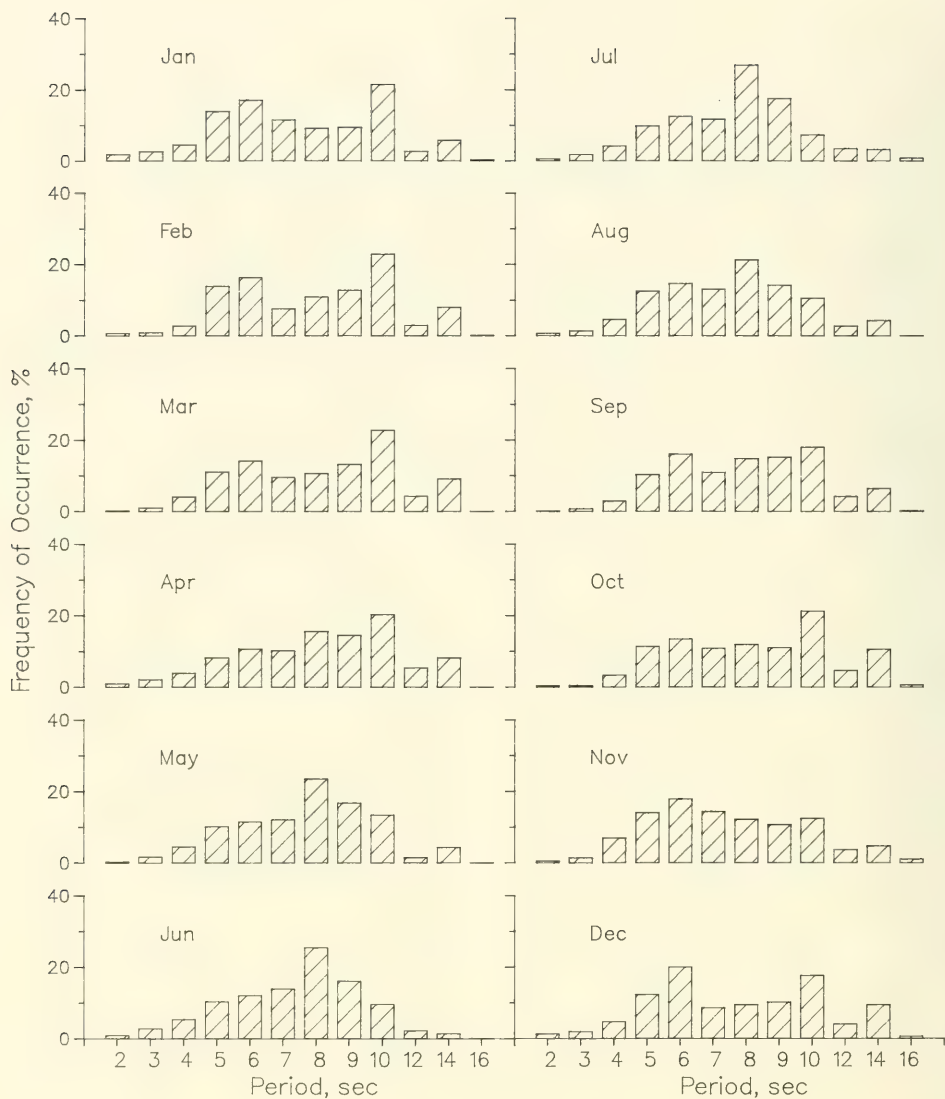


Figure B7. 1980-1988 monthly wave period distributions for Gage 630

Table B5  
1988 Persistence of  $H_{mo}$  for Gage 630

| Height<br>(m) | Consecutive Day(s) or Longer |    |    |    |    |   |   |   |    |    |    |    |    |    |    |    |    |    |     |
|---------------|------------------------------|----|----|----|----|---|---|---|----|----|----|----|----|----|----|----|----|----|-----|
|               | 1                            | 2  | 3  | 4  | 5  | 6 | 7 | 8 | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19+ |
| 0.5           |                              | 15 | 13 |    | 12 |   |   |   | 10 | 9  |    | 8  | 7  |    |    |    | 6  |    | 5   |
| 1.0           | 52                           | 41 | 25 | 17 | 12 |   | 7 | 6 | 4  | 3  | 2  |    |    |    |    |    |    |    | 1   |
| 1.5           | 44                           | 21 | 12 |    | 3  | 1 |   |   |    |    |    |    |    |    |    |    |    |    |     |
| 2.0           | 20                           | 5  | 1  |    |    |   |   |   |    |    |    |    |    |    |    |    |    |    |     |
| 2.5           | 7                            | 2  | 1  |    |    |   |   |   |    |    |    |    |    |    |    |    |    |    |     |
| 3.0           | 4                            |    | 1  |    |    |   |   |   |    |    |    |    |    |    |    |    |    |    |     |
| 3.5           | 1                            |    |    |    |    |   |   |   |    |    |    |    |    |    |    |    |    |    |     |
| 4.0           | 1                            |    |    |    |    |   |   |   |    |    |    |    |    |    |    |    |    |    |     |

Table B6  
1980 through 1988 Persistence of  $H_{mo}$  for Gage 630

| Height<br>(m) | Consecutive Day(s) or Longer |    |    |    |    |    |    |   |    |    |    |    |    |    |    |    |    |    |     |
|---------------|------------------------------|----|----|----|----|----|----|---|----|----|----|----|----|----|----|----|----|----|-----|
|               | 1                            | 2  | 3  | 4  | 5  | 6  | 7  | 8 | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19+ |
| 0.5           | 21                           | 19 | 16 | 15 | 14 | 13 | 12 |   | 10 |    | 9  |    | 8  | 7  |    | 5  | 4  |    | 3   |
| 1.0           | 50                           | 33 | 25 | 17 | 13 | 10 | 7  | 5 | 4  | 3  | 2  |    |    |    |    |    | 1  |    |     |
| 1.5           | 39                           | 21 | 11 | 6  | 4  | 2  |    | 1 |    |    |    |    |    |    |    |    |    |    |     |
| 2.0           | 22                           | 11 | 4  |    |    |    |    |   |    |    |    |    |    |    |    |    |    |    |     |
| 2.5           | 10                           | 5  | 2  |    |    |    |    |   |    |    |    |    |    |    |    |    |    |    |     |
| 3.0           | 6                            | 2  |    |    |    |    |    |   |    |    |    |    |    |    |    |    |    |    |     |
| 3.5           | 3                            | 1  |    |    |    |    |    |   |    |    |    |    |    |    |    |    |    |    |     |
| 4.0           | 1                            |    |    |    |    |    |    |   |    |    |    |    |    |    |    |    |    |    |     |

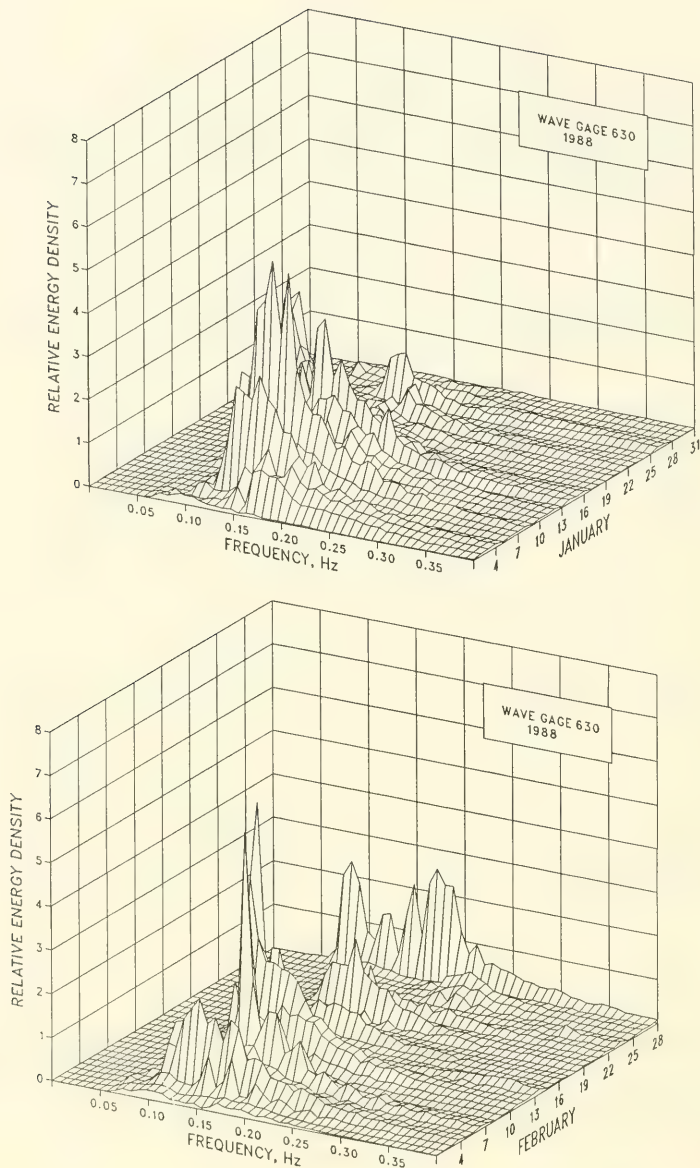


Figure B8. 1988 monthly spectra for Gage 630  
(Sheet 1 of 6)

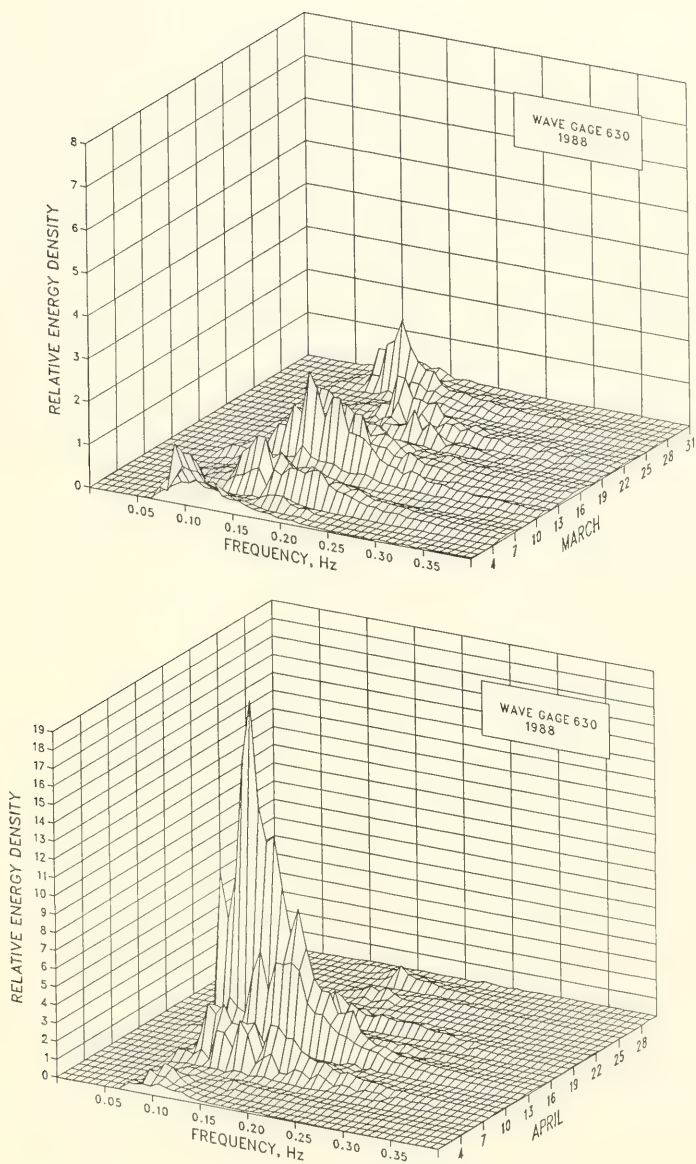


Figure B8. (Sheet 2 of 6)

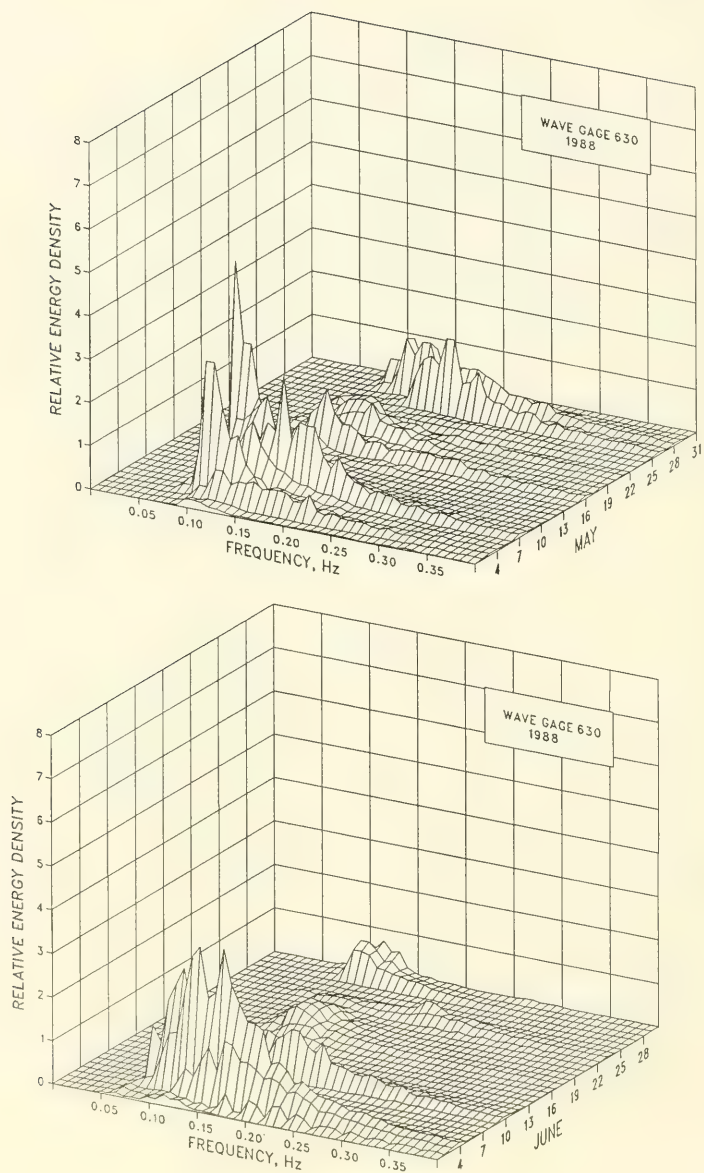


Figure B8. (Sheet 3 of 6)



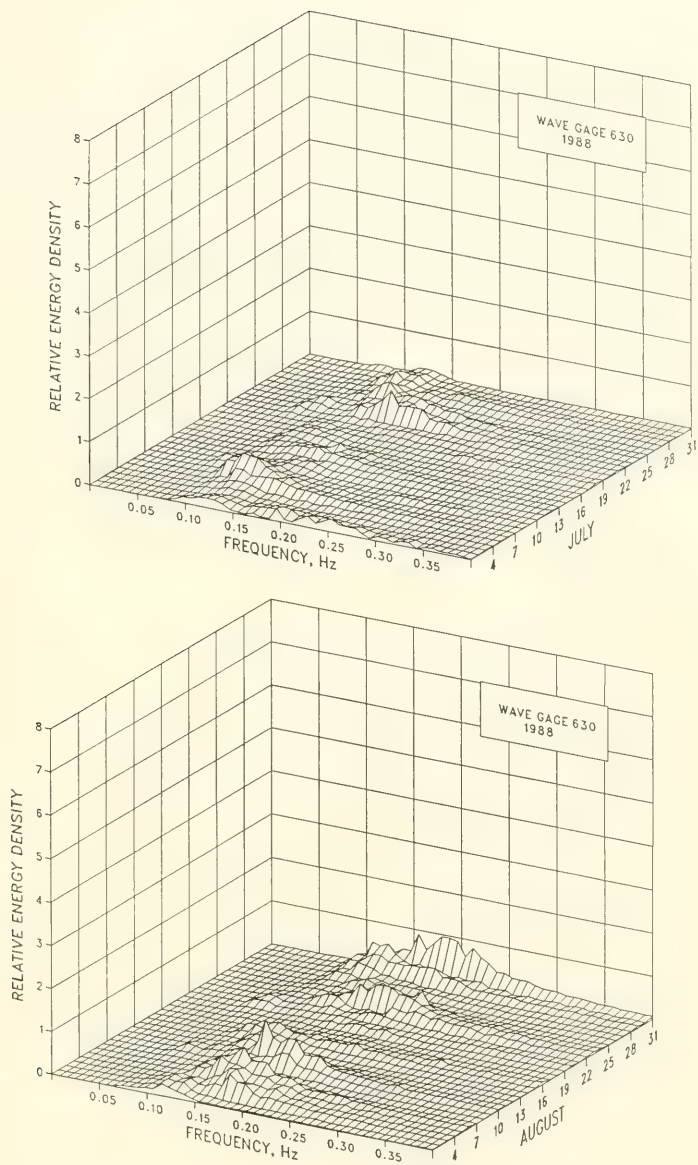


Figure B8. (Sheet 4 of 6)

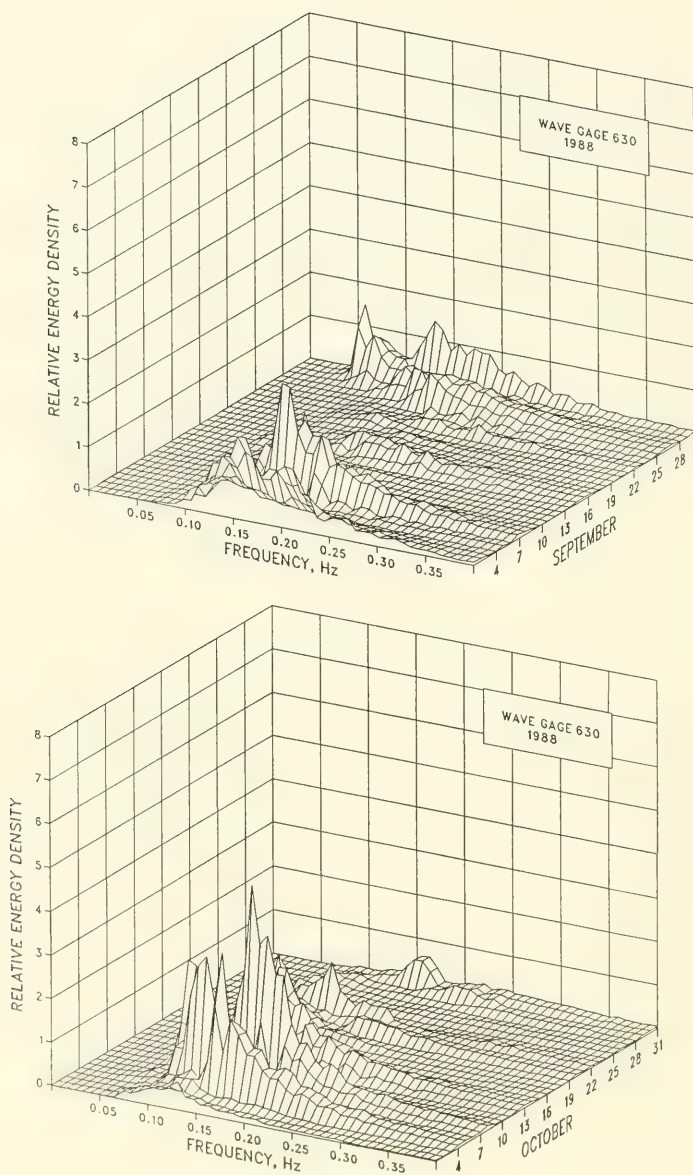


Figure B8. (Sheet 5 of 6)

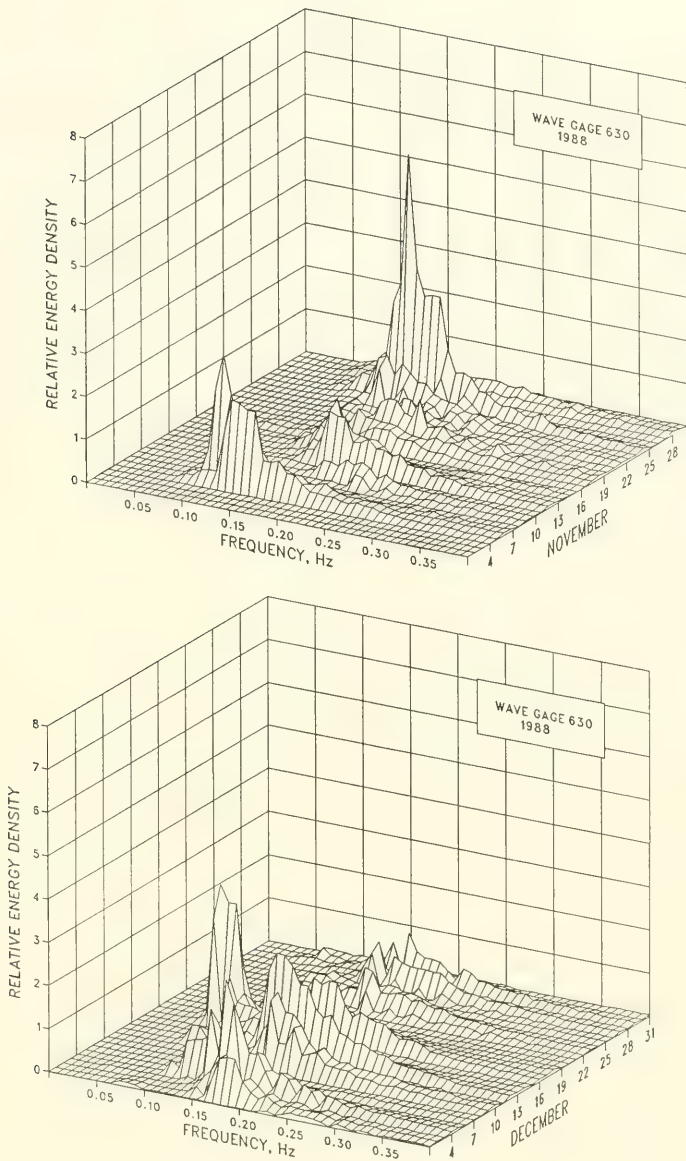


Figure B8. (Sheet 6 of 6)

Table B7  
Wave Statistics for Gage 630

| Month  | 1988   |           |         |      |        |           |             | 1980-1988 |           |         |          |        |           |             |
|--------|--------|-----------|---------|------|--------|-----------|-------------|-----------|-----------|---------|----------|--------|-----------|-------------|
|        | Height |           |         | Date | Period |           |             | Height    |           |         | Date     | Period |           |             |
|        | Mean   | Std. Dev. | Extreme |      | Mean   | Std. Dev. | Number Obs. | Mean      | Std. Dev. | Extreme |          | Mean   | Std. Dev. | Number Obs. |
|        |        |           |         |      |        |           |             |           |           |         |          |        |           |             |
| Jan    | 1.2    | 0.6       | 3.1     | 8    | 8.5    | 3.1       | 124         | 1.2       | 0.7       | 4.5     | 1983     | 8.0    | 2.8       | 950         |
| Feb    | 1.1    | 0.6       | 2.7     | 28   | 7.8    | 2.6       | 116         | 1.2       | 0.7       | 5.1     | 1987     | 8.5    | 2.6       | 905         |
| Mar    | 1.0    | 0.4       | 2.2     | 11   | 7.8    | 2.2       | 121         | 1.2       | 0.7       | 4.7     | 1983     | 8.6    | 2.7       | 998         |
| Apr    | 1.3    | 0.9       | 5.2     | 13   | 8.9    | 3.1       | 116         | 1.1       | 0.7       | 5.2     | 1988     | 8.7    | 2.8       | 975         |
| May    | 1.0    | 0.5       | 2.2     | 7    | 8.6    | 1.6       | 111         | 0.9       | 0.5       | 3.3     | 1986     | 8.1    | 2.3       | 983         |
| Jun    | 0.8    | 0.5       | 2.4     | 4    | 8.0    | 2.0       | 101         | 0.8       | 0.4       | 2.4     | 1988     | 7.7    | 2.2       | 927         |
| Jul    | 0.7    | 0.2       | 1.1     | 1    | 7.9    | 1.7       | 121         | 0.7       | 0.3       | 2.1     | 1985     | 8.1    | 2.5       | 948         |
| Aug    | 0.8    | 0.3       | 1.6     | 31   | 7.4    | 2.1       | 119         | 0.8       | 0.5       | 3.6     | 1981     | 7.9    | 2.4       | 949         |
| Sep    | 1.0    | 0.5       | 2.1     | 8    | 7.8    | 2.5       | 111         | 1.0       | 0.6       | 6.1     | 1985     | 8.5    | 2.6       | 960         |
| Oct    | 1.0    | 0.5       | 2.6     | 8    | 9.3    | 2.7       | 108         | 1.2       | 0.7       | 4.3     | 1982     | 8.7    | 2.8       | 1039        |
| Nov    | 1.1    | 0.5       | 2.4     | 24   | 6.8    | 2.1       | 94          | 1.2       | 0.7       | 4.1     | 1981     | 7.9    | 2.8       | 861         |
| Dec    | 1.0    | 0.5       | 2.6     | 4    | 7.6    | 3.2       | 118         | 1.1       | 0.7       | 5.6     | 1980     | 8.3    | 3.0       | 887         |
| Annual | 1.0    | 0.6       | 5.2     | Apr  | 8.0    | 2.6       | 1360        | 1.0       | 0.6       | 6.1     | Sep 1985 | 8.3    | 2.6       | 11382       |

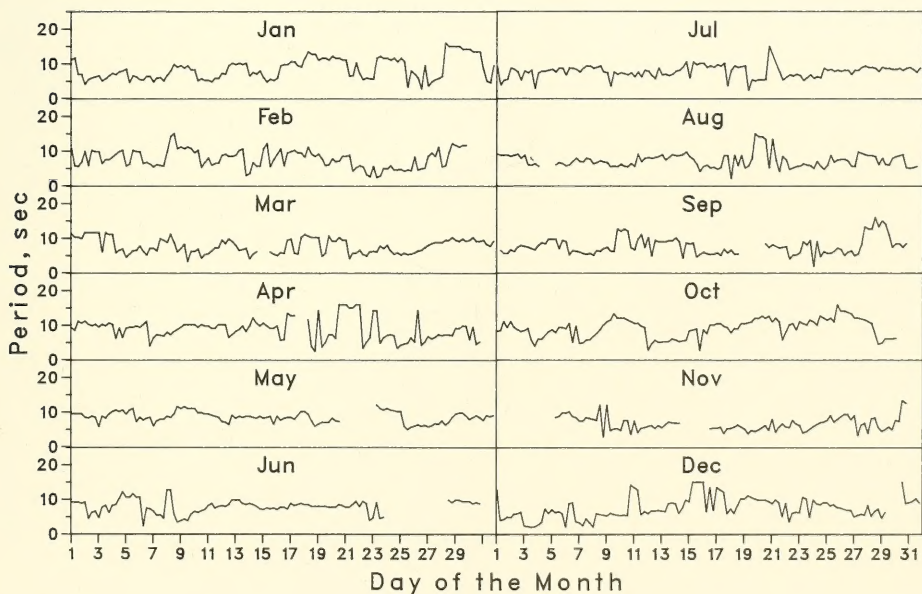
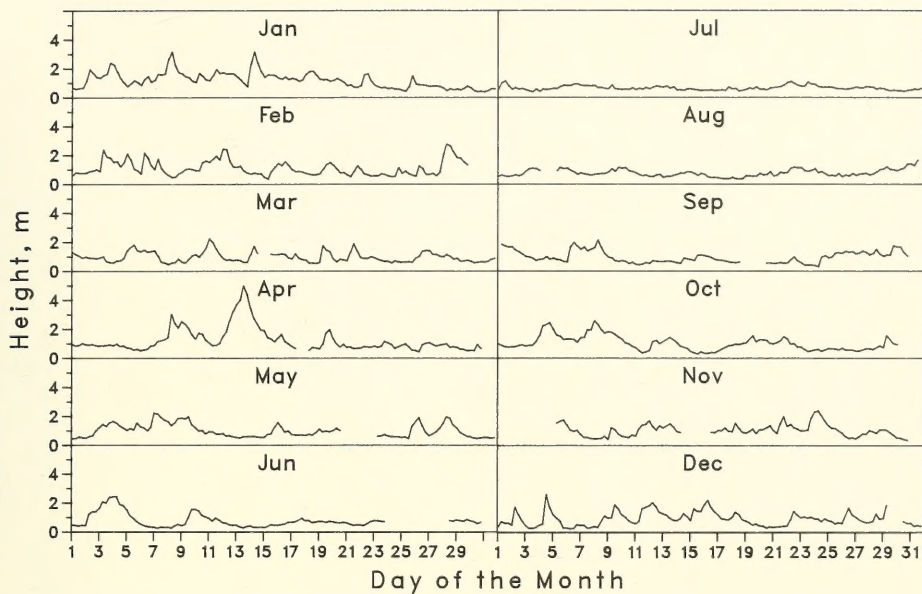


Figure B9. Time-histories of wave height and period  
for Gage 630



